

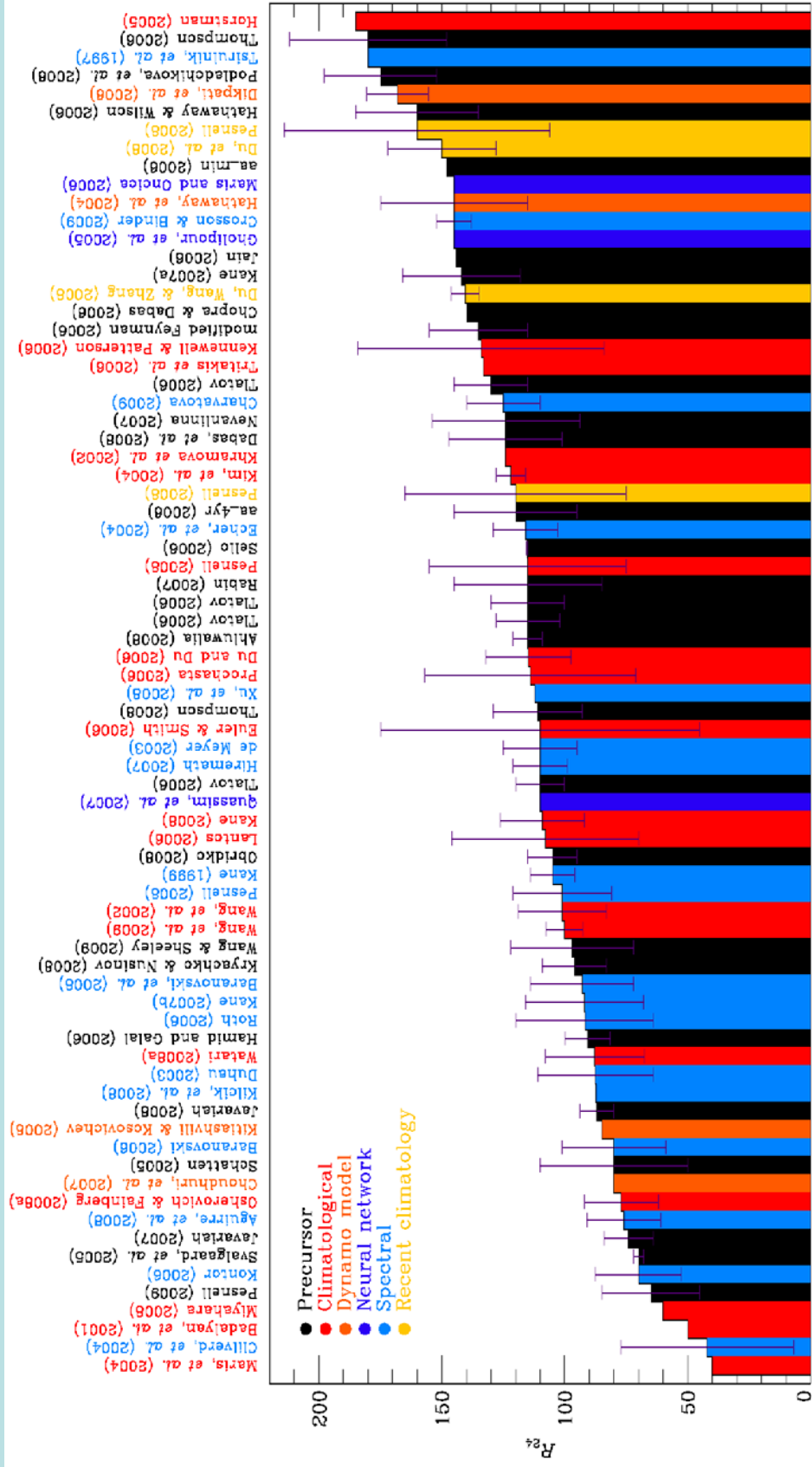
Predicting the Solar Cycle

Leif Svalgaard
Stanford University

Solar Analogs II
Flagstaff, AZ, Sept. 22, 2009

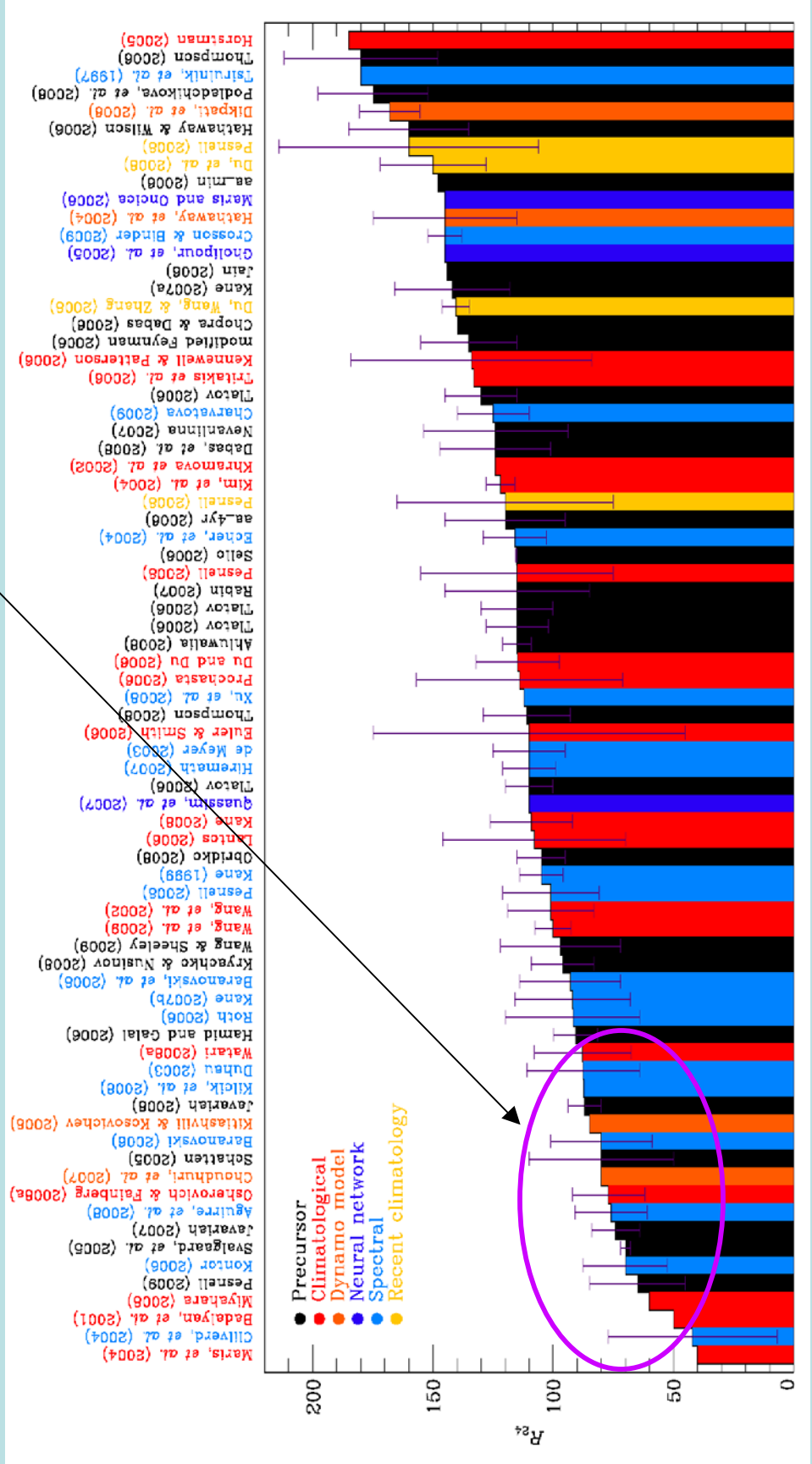
State of the Art: Predicting Cycle 24

Predictions sent to the Prediction Panel



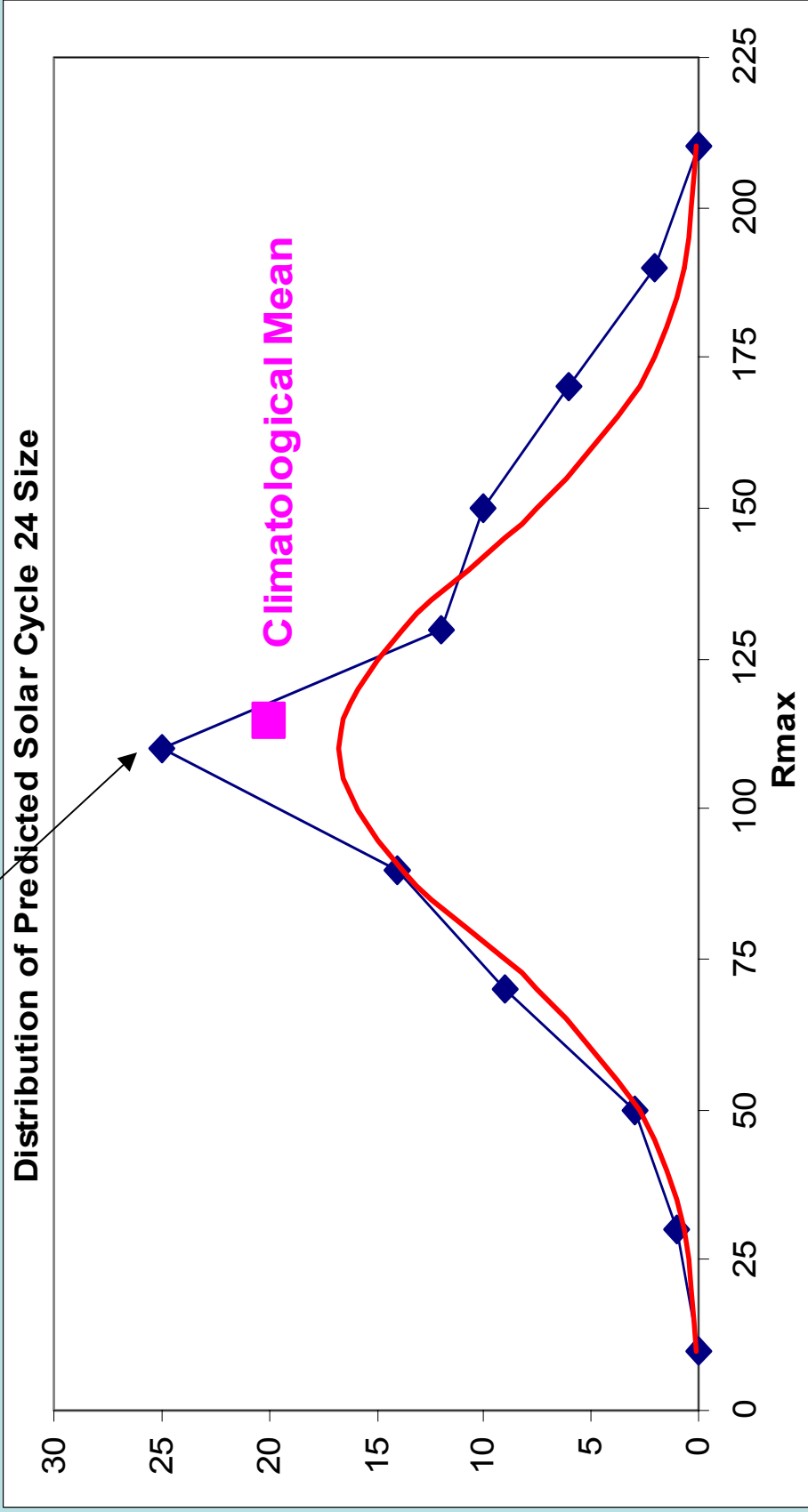
State of the Art: Predicting Cycle 24

What the Sun seems to be doing



Near Normal Distribution = No Skill

Some preference for Climatological Mean



Early Optimism and PR Effort

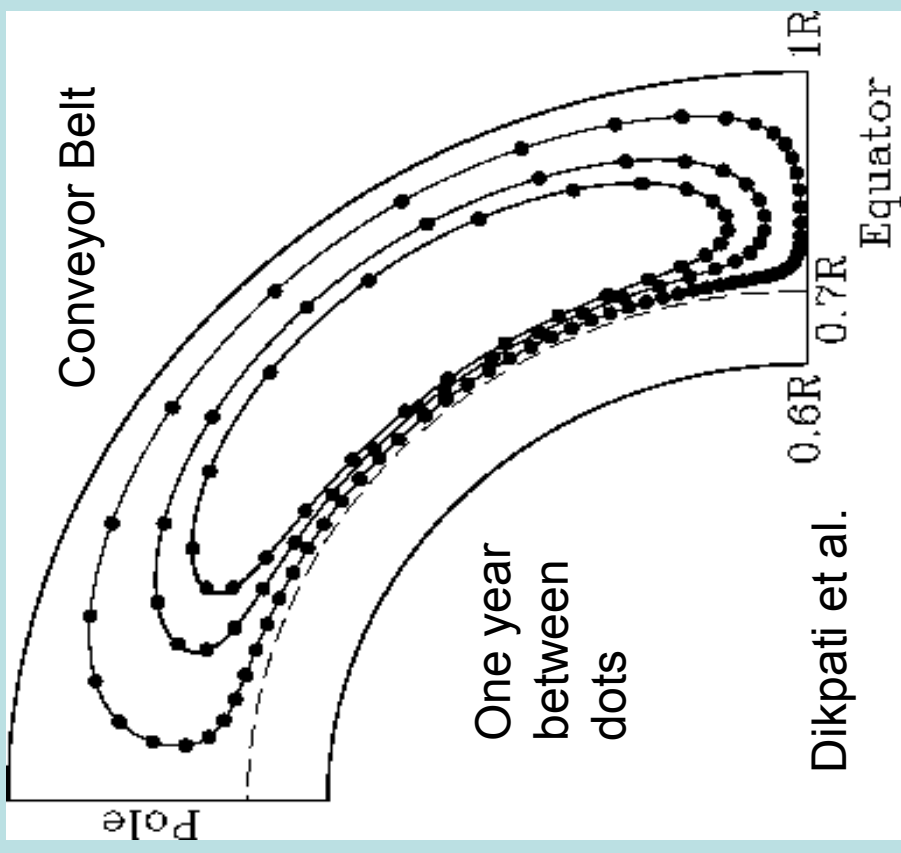
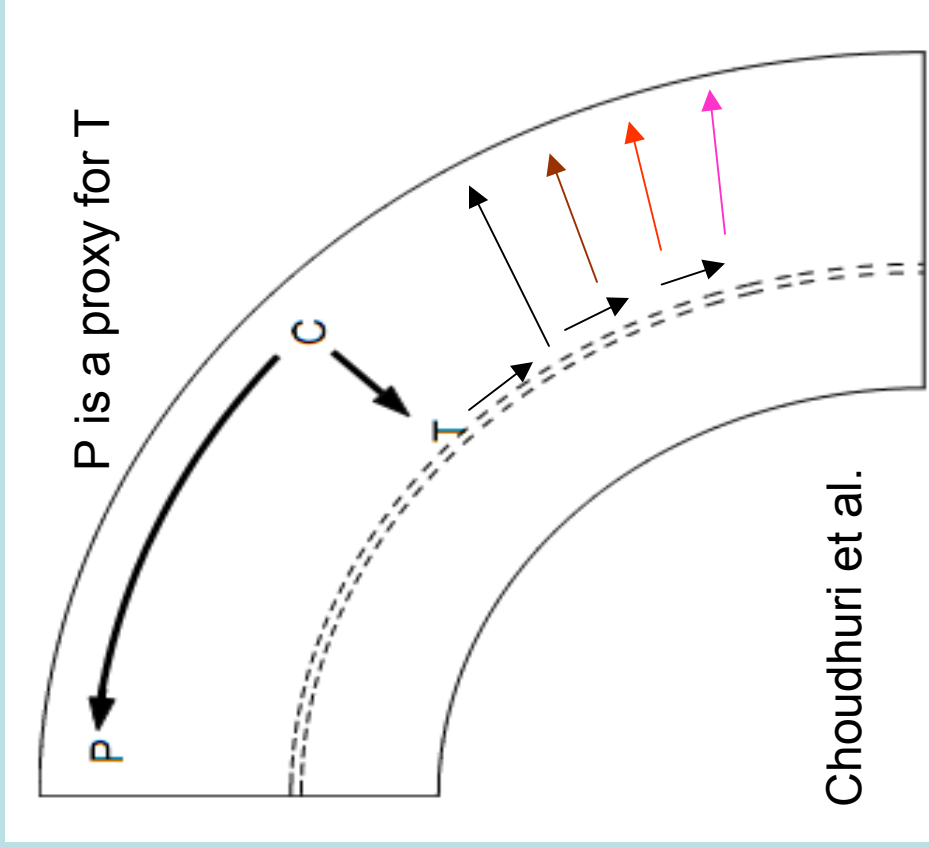
- “The next sunspot cycle will be 30-50% stronger than the last one and begin as much as a year late, according to a *breakthrough* forecast using a computer model of solar dynamics developed by scientists at the National Center for Atmospheric Research (NCAR).”

2004-2006

Flux Transport Dynamo Models

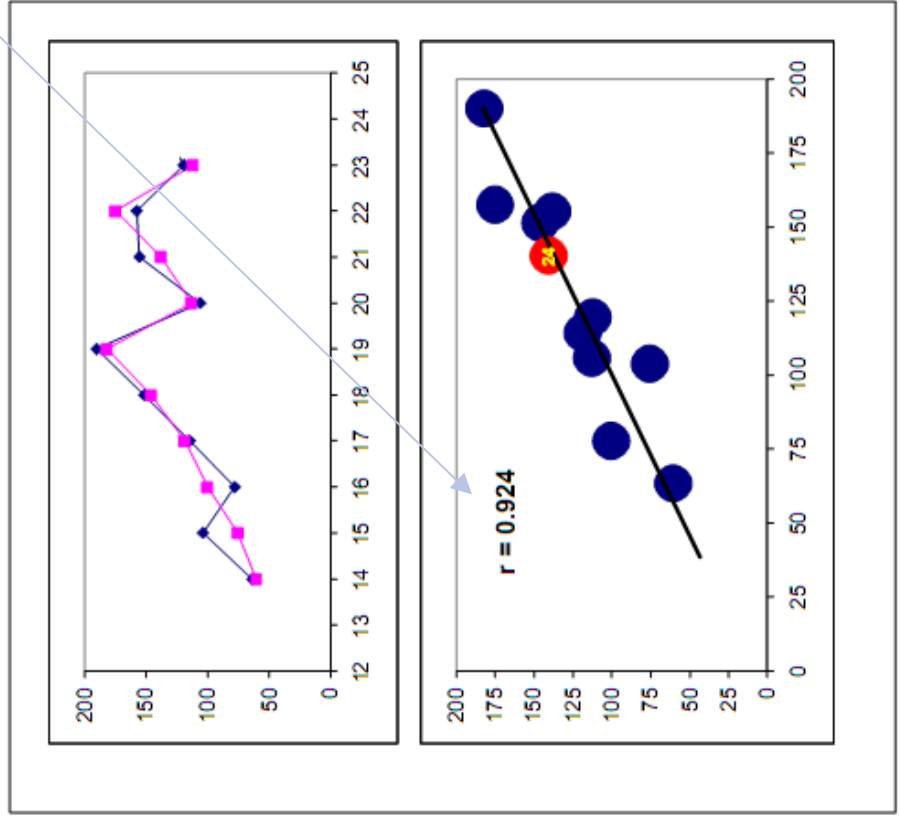
- Dikpati, M., de Toma, G., Gilman, P.A.: Predicting the strength of solar cycle 24 using a flux-transport dynamo-based tool, Geophys. Res. Lett., 33, L05102, 2006.
 $R_{\max 24} = 160-185$
- Choudhuri, A.R., Chatterjee, P., Jiang, J.: Predicting Solar Cycle 24 with a solar dynamo model, Phys. Rev. Lett., 98, 131103, 2007.
 $R_{\max 24} = 75$
- Difference is primarily due to different assumptions about the diffusivity of magnetic flux into the Sun [high = weak cycle]

High Diffusivity: Left Low Diffusivity (Advection): Right

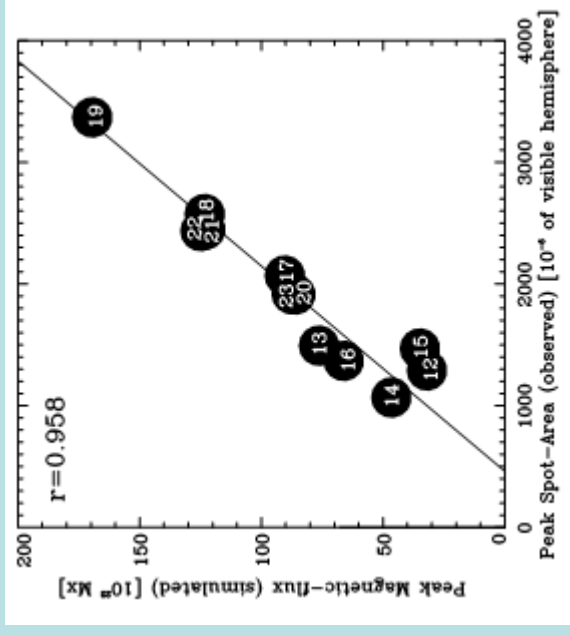


Grow-N-Crash 'Model'

Easy to get a high correlation



Dikpati et al. 2006



COMPUTE ALPHA = 0.238
COMPUTE R-TOP = 200

PREDICT-CYCLE.

```

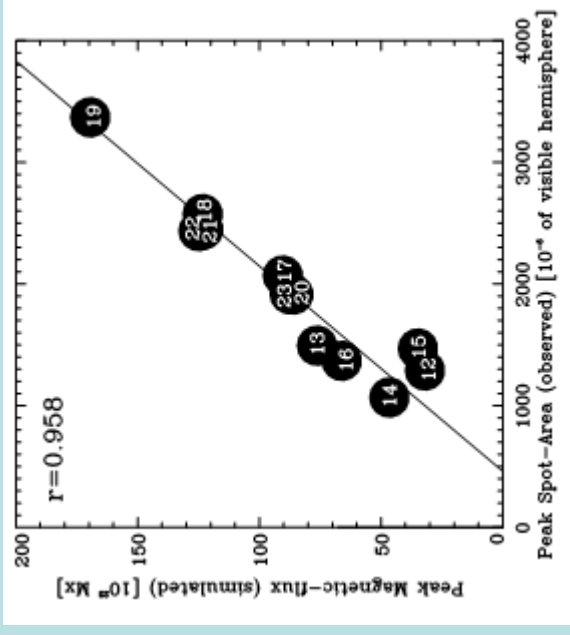
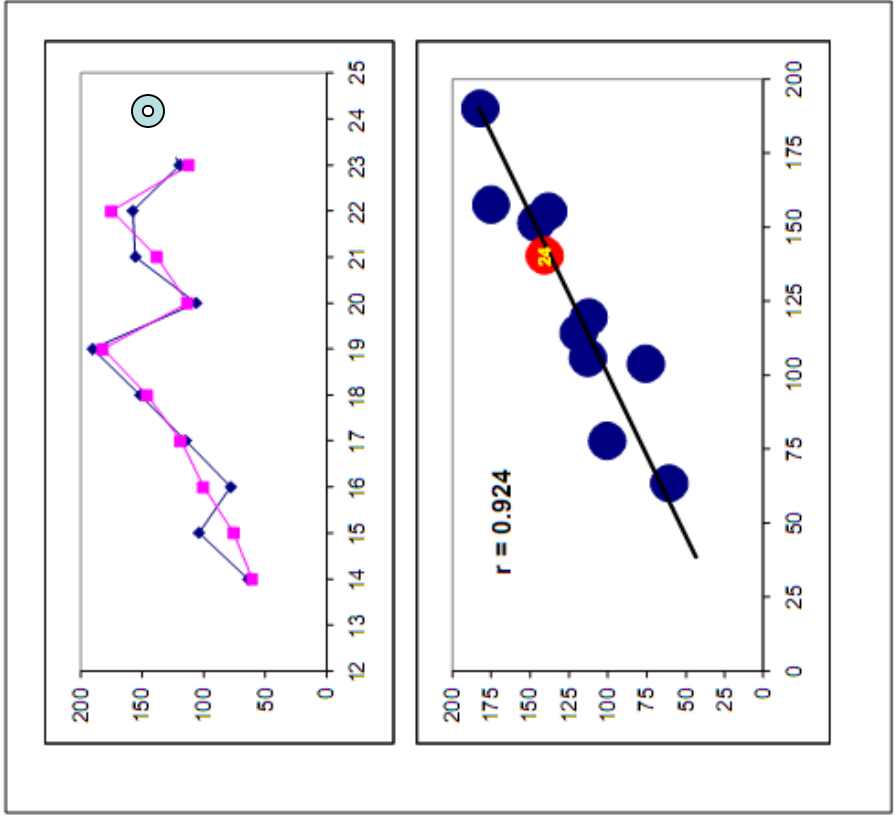
COMPUTE P-NBR = C-NBR - 1
COMPUTE R-ADD = R-OBS(P-NBR) * ALPHA
COMPUTE R-PRE(C-NBR) = R-PRE(P-NBR) + R-ADD
IF R-PRE(C-NBR) > R-TOP
  COMPUTE R-ADJ = (R-OBS(P-NBR) ** 0.5) * 5
  COMPUTE R-PRE(C-NBR) = R-PRE(C-NBR) - R-ADJ - R-ADD
    
```

Intermittency from threshold effects

Grow-N-Crash 'Model'

Easy to get a high correlation

Dikpati et al. 2006



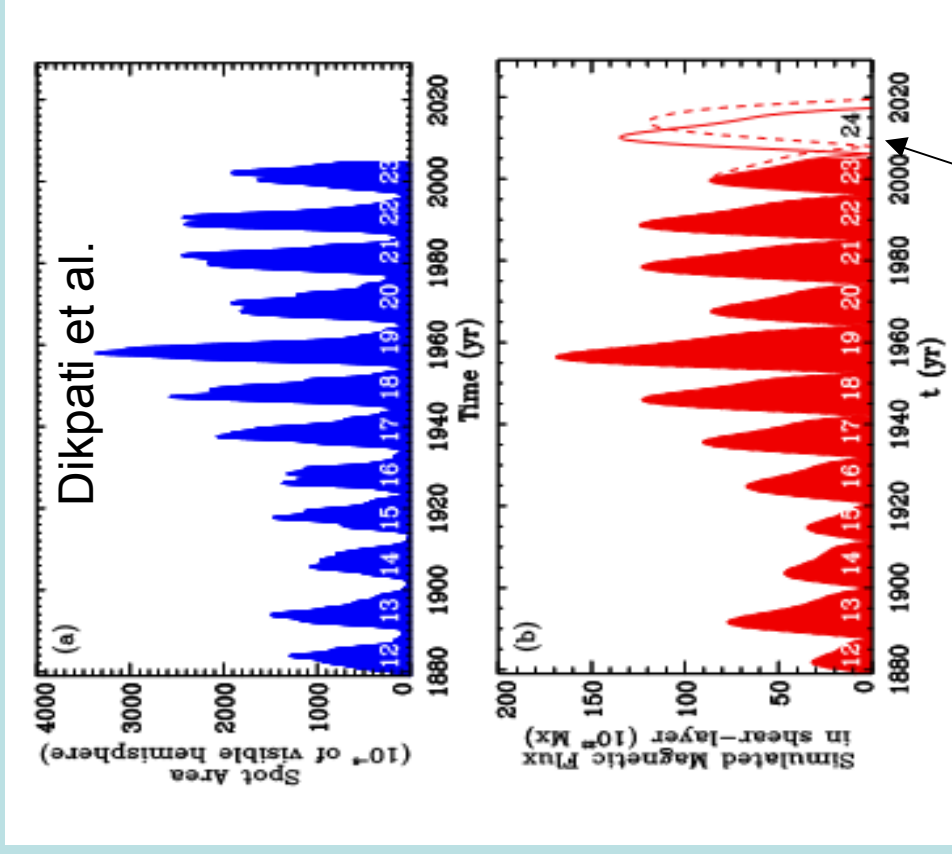
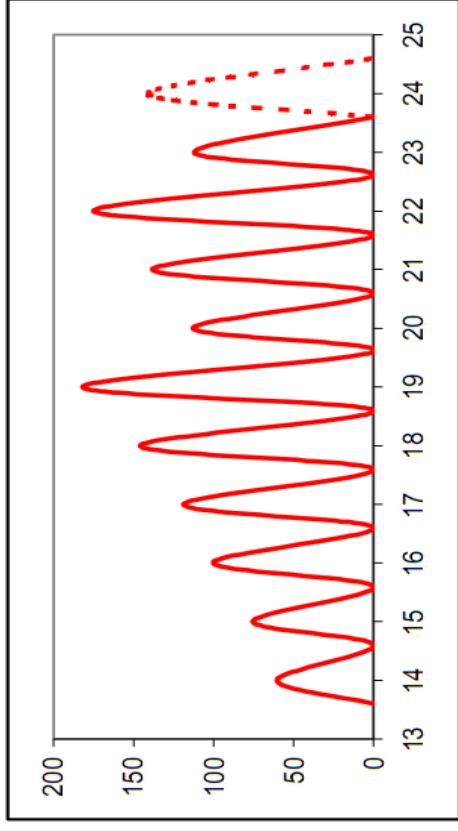
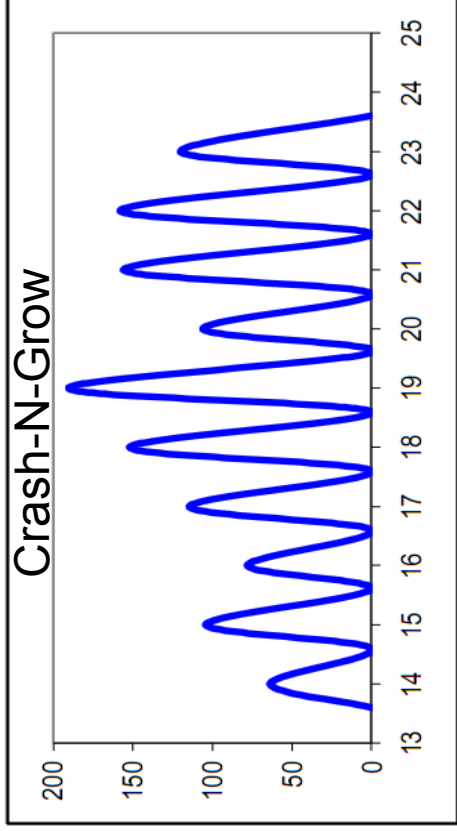
COMPUTE ALPHA = 0.238
COMPUTE R-TOP = 200

PREDICT-CYCLE.

```

COMPUTE P-NBR = C-NBR - 1
COMPUTE R-ADD = R-OBS(P-NBR) * ALPHA
COMPUTE R-PRE(C-NBR) = R-PRE(P-NBR) + R-ADD
IF R-PRE(C-NBR) > R-TOP
  COMPUTE R-ADJ = (R-OBS(P-NBR) ** 0.5) * 5
  COMPUTE R-PRE(C-NBR) = R-PRE(C-NBR) - R-ADJ - R-ADD
    
```

Supply a Scaled Standard Cycle Body to get 'Stunning' Correlation



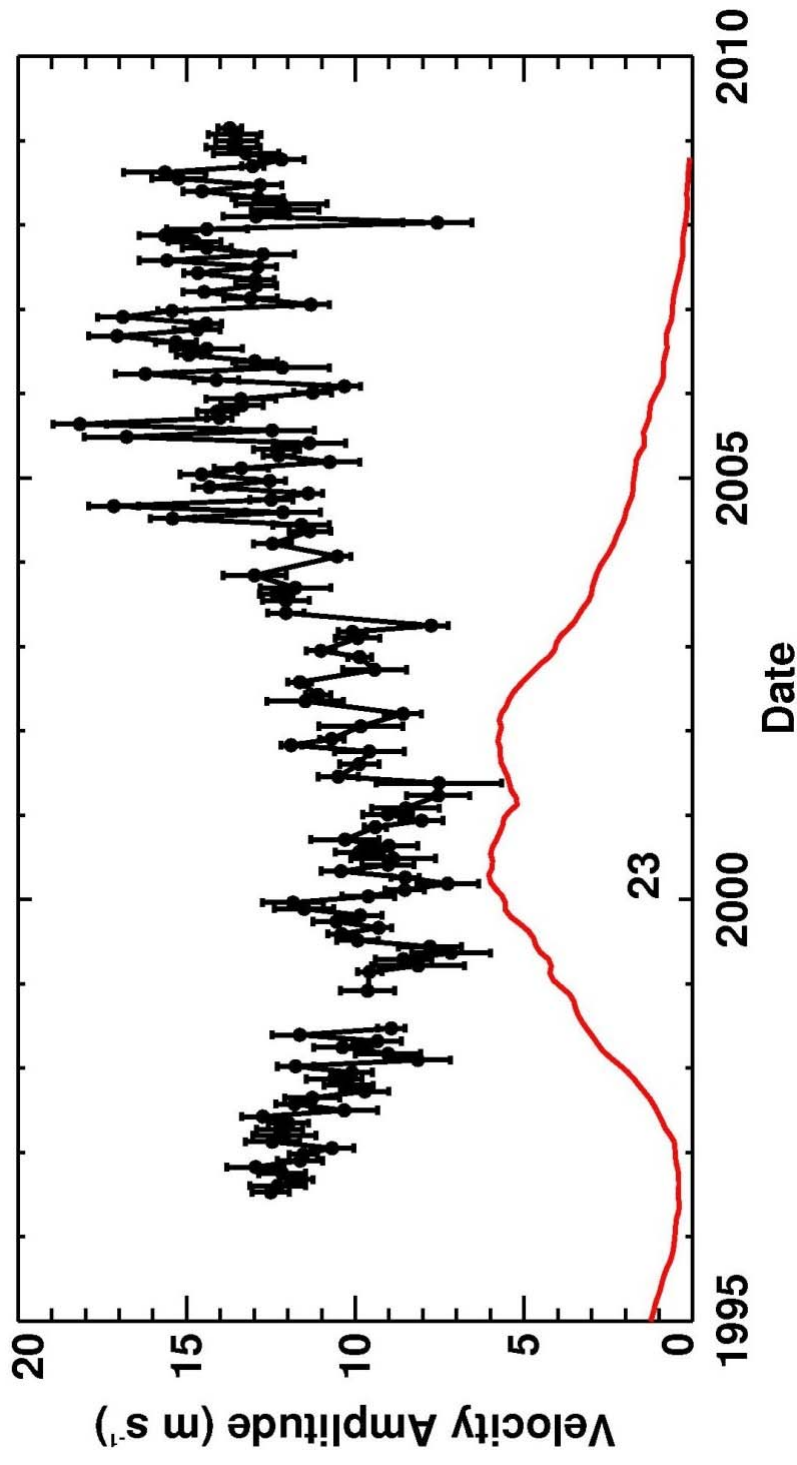
Dikpati et al. assumed constant Meridional Circulation, except for cycle 24 10

Meridional Circulation

Both (Dikpati, Choudhuri) of these Flux Transport Dynamo Models produce strong polar fields and short cycles when the meridional flow is fast.

However: “Measurements of the meridional flow over Cycle 23 now show that on the approach to Cycle 24 minimum in 2008 to speeds significantly higher than were seen at the previous minimum (David Hathaway, SOHO-23)”

Meridional Circulation



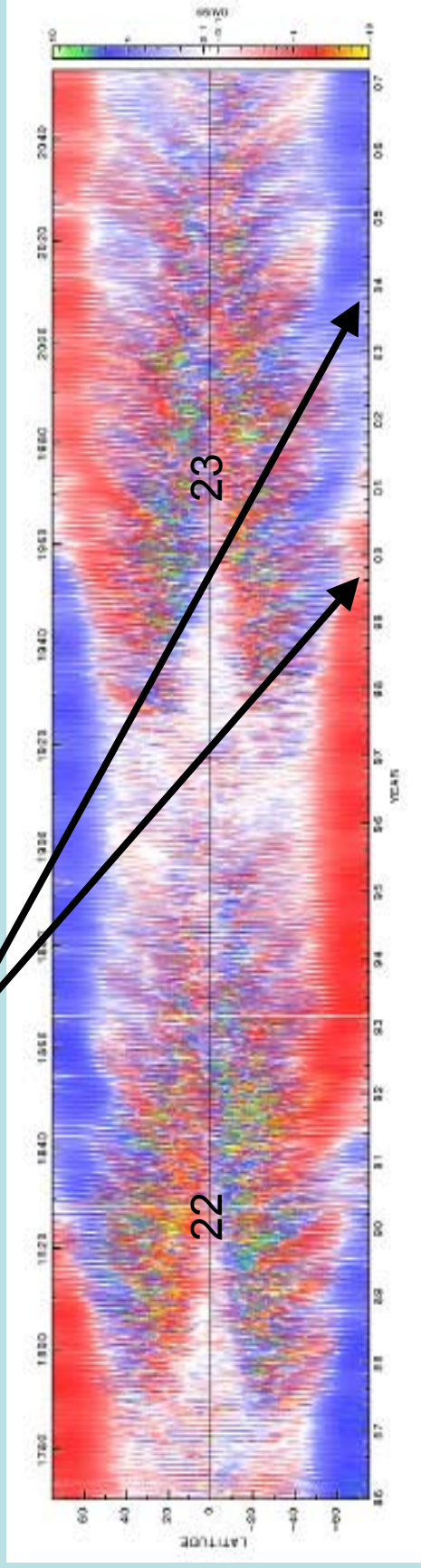
Lisa Rightmire, David Hathaway (2009):
Cross-correlating full-disk magnetograms

‘Flux Transport Models Not Ready Yet’

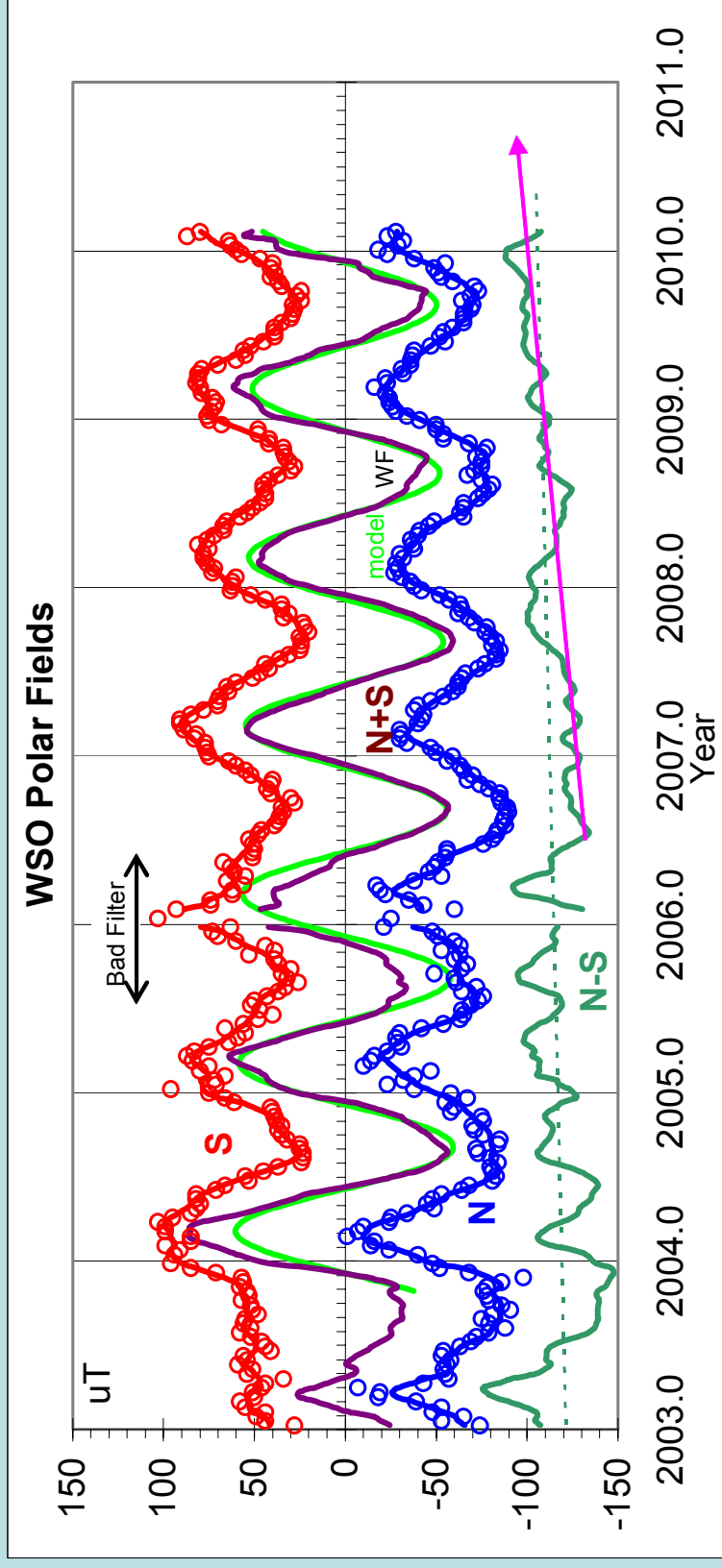
- “In these models this higher meridional flow speed should produce strong polar fields and a short solar cycle contrary to the observed behavior.
- “These observations, along with others, suggest that Flux Transport Dynamo Models do not properly capture solar cycle behavior and are not yet ready to provide predictions of solar cycle behavior.

Is This Too Harsh?

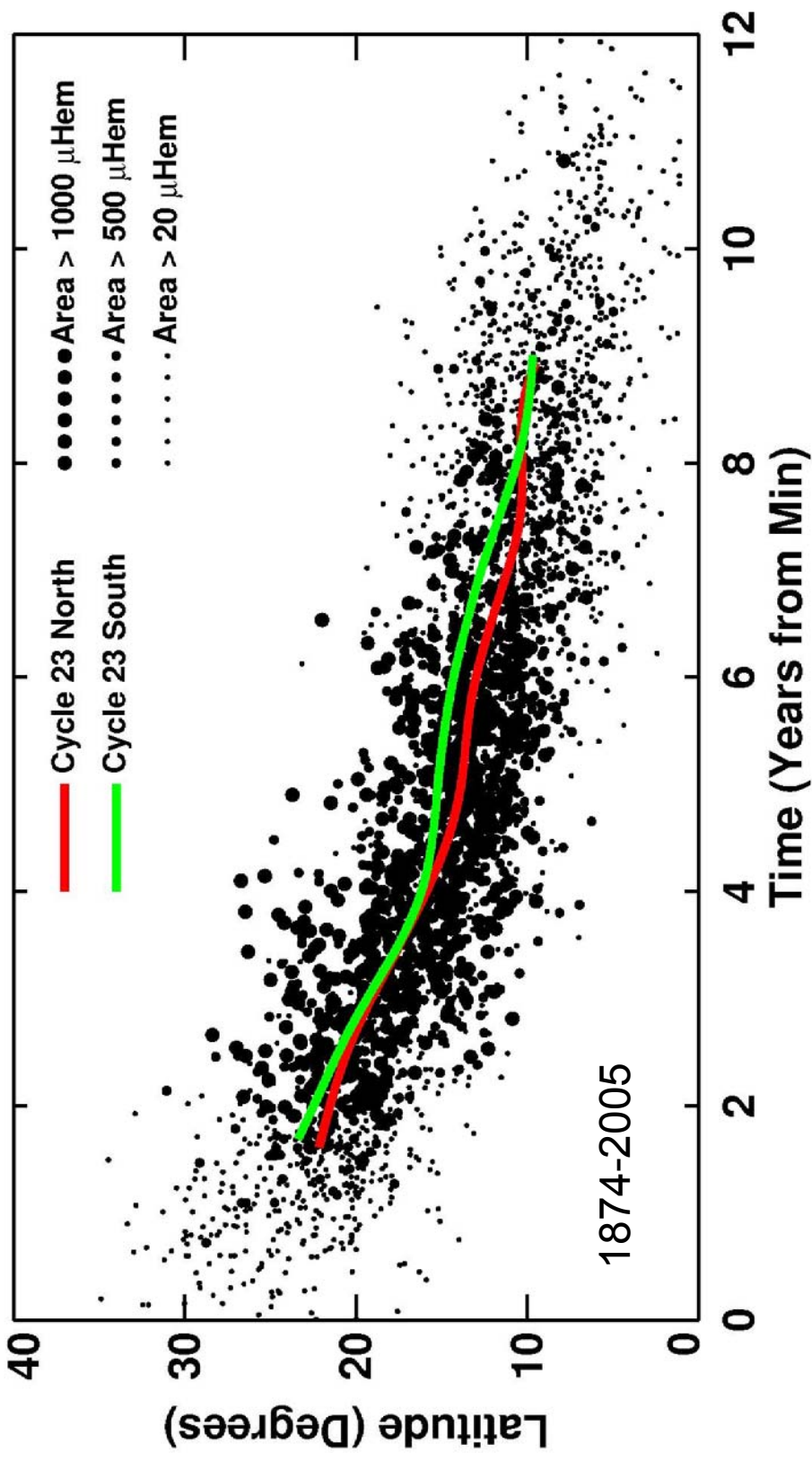
- The polar fields were built several years ago *before* the increase in the Meridional circulation [the polar fields were essentially established by mid-2003]



And Have Not Increased Since Then,
rather Beginning to Show a Decrease



Latitudes of Active Regions During Cycle 23 were not Unusual



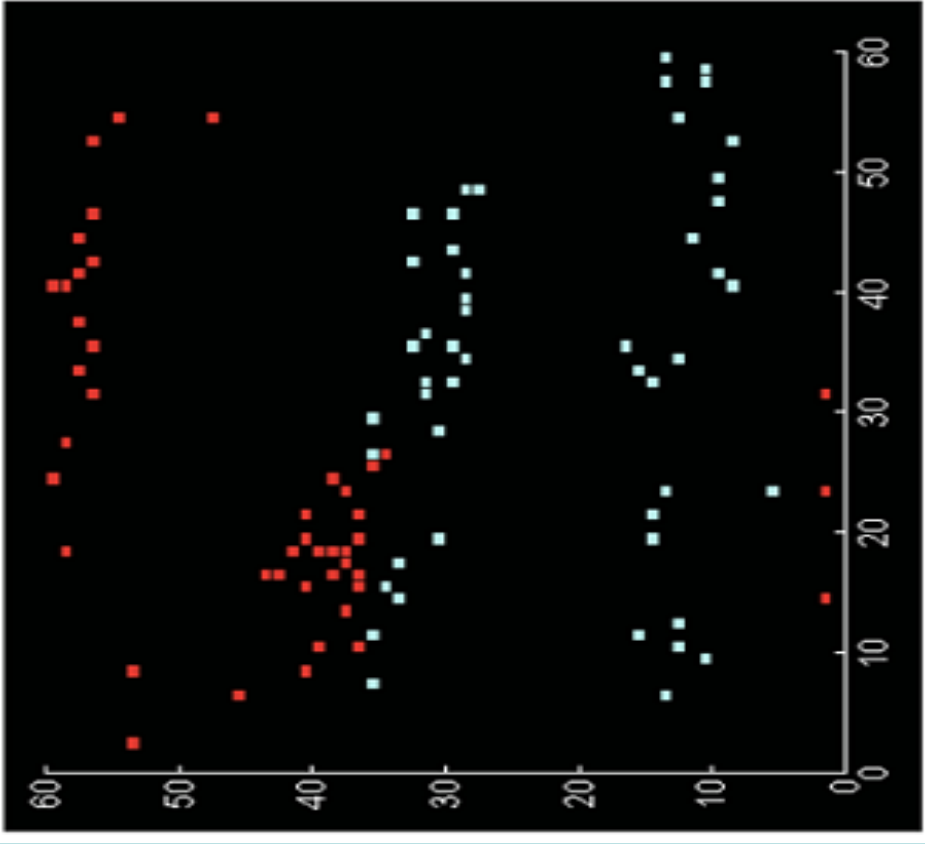
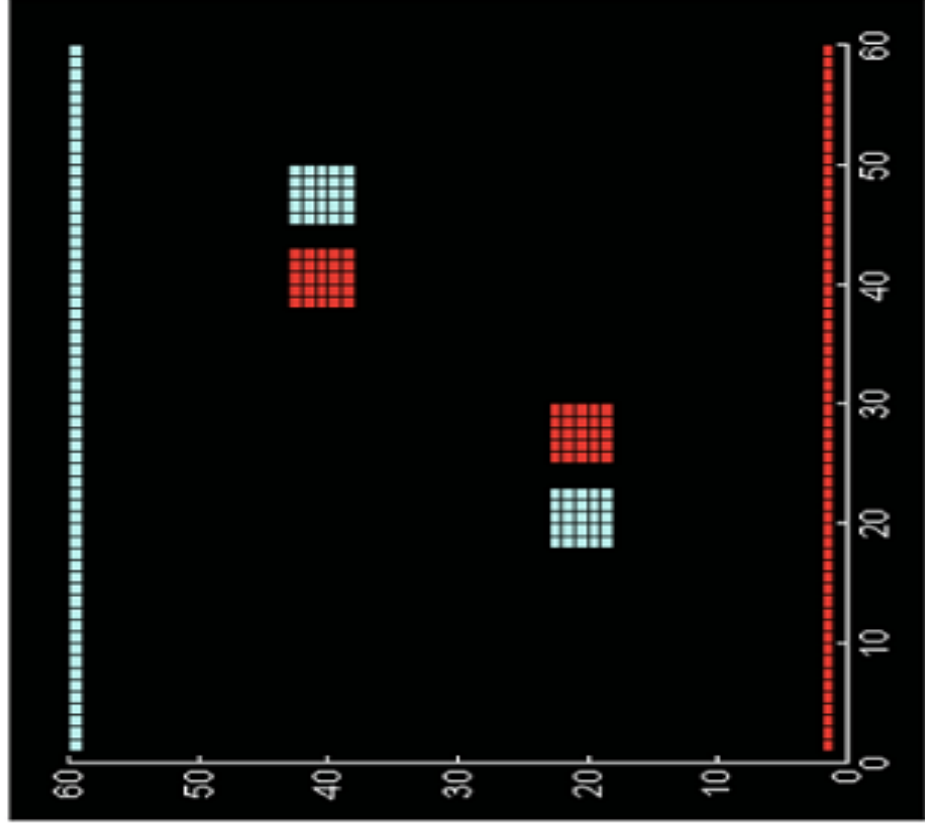
Issues with Meridional Circulation

- The question is not whether the M.C. is there or not, but rather what role it plays in the solar cycle, probably hinging on the value of the turbulent diffusivity.
- An unknown is the degree to which M.C. is affected by back-reaction from the Lorentz force associated with the dynamo-generated magnetic field (chicken and egg).
- The form and speed of the equatorward return flow in the lower convective zone is at present unknown.

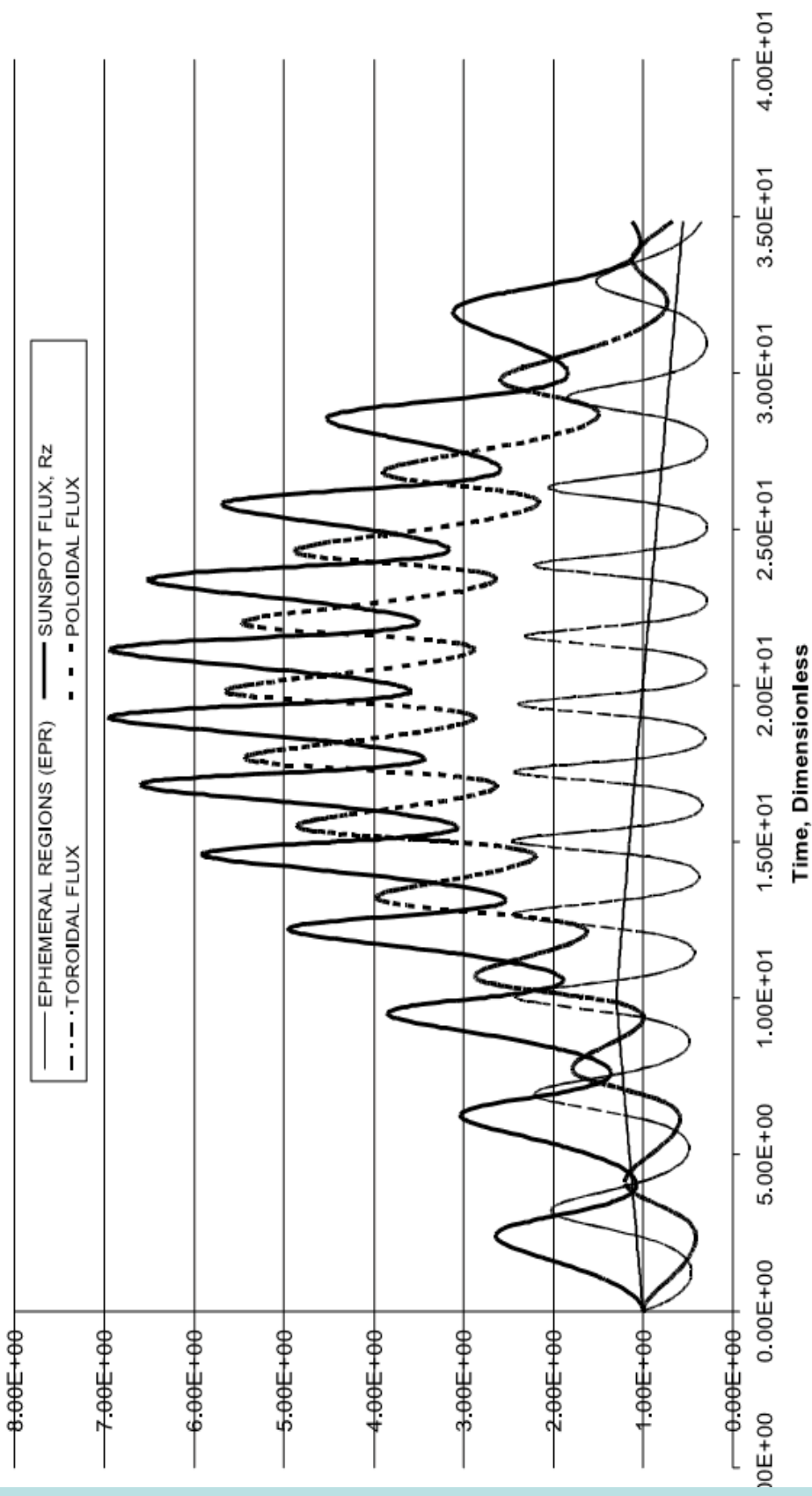
Perhaps a Shallow Dynamo?

Ken Schatten [*Solar Physics*, 255, 3-38, 2009] explores the possibility of sunspots being a *surface* phenomenon [being the coalescence of smaller magnetic features as observations seem to indicate] and that the solar dynamo is shallow rather than operating at the tachocline, based on his Cellular Automata model of solar activity.

Schatten's Cellular Automata Model

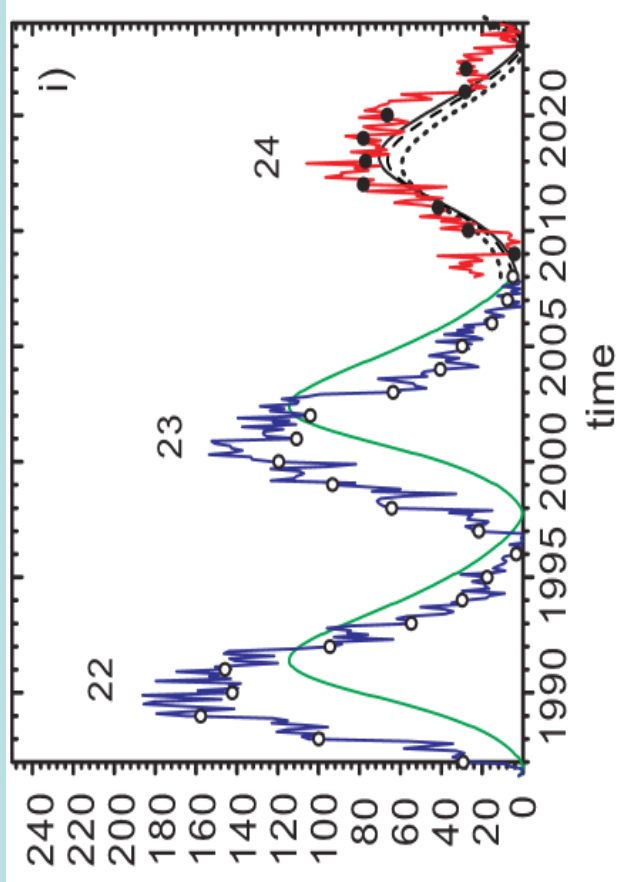
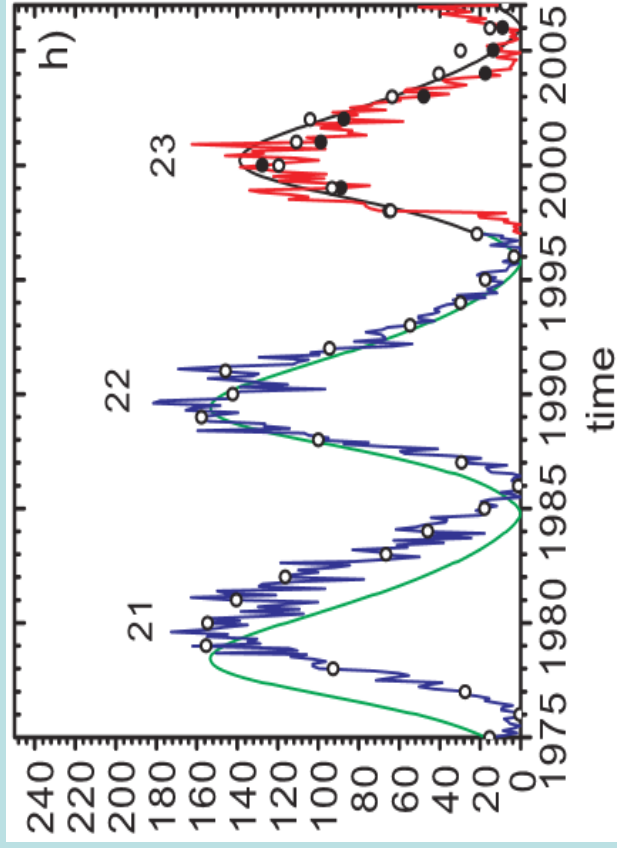


In the CA Model, the Polar Flux also Predicts the Sunspot Flux



Other Dynamo Models

The Ensemble Kalman Filter (EnKF) method has been used to assimilate the sunspot number data into a non-linear α - Ω mean-field dynamo model, which takes into account the dynamics of turbulent magnetic helicity.



Back to Empirical Predictions?

With predictions based on Flux Transport
Dynamos in doubt or less enthusiastically
embraced (and the Shallow Dynamo and
the EnKF approach not generally pursued)
we may be forced back to Precursor
Techniques where some observed
features are thought to presage future
activity.

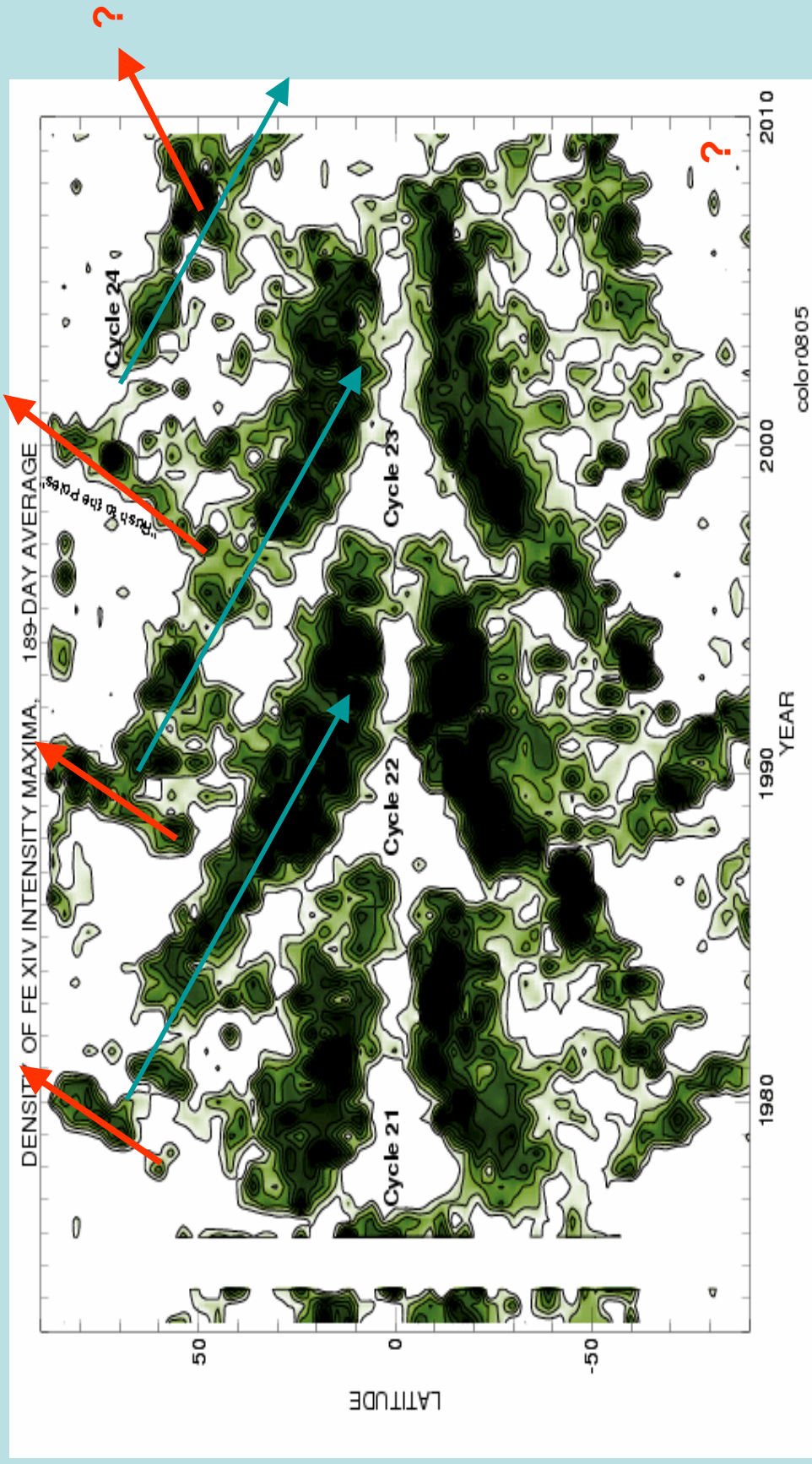
Precursors

- Coronal Structure [Rush to the Poles]
- Torsional Oscillation [At Depth]
- H-alpha Maps [Magnetic Field Proxy]
- Geomagnetic Activity [Solar Wind Proxies]
- Open Flux at Minimum

And that old stand-by:

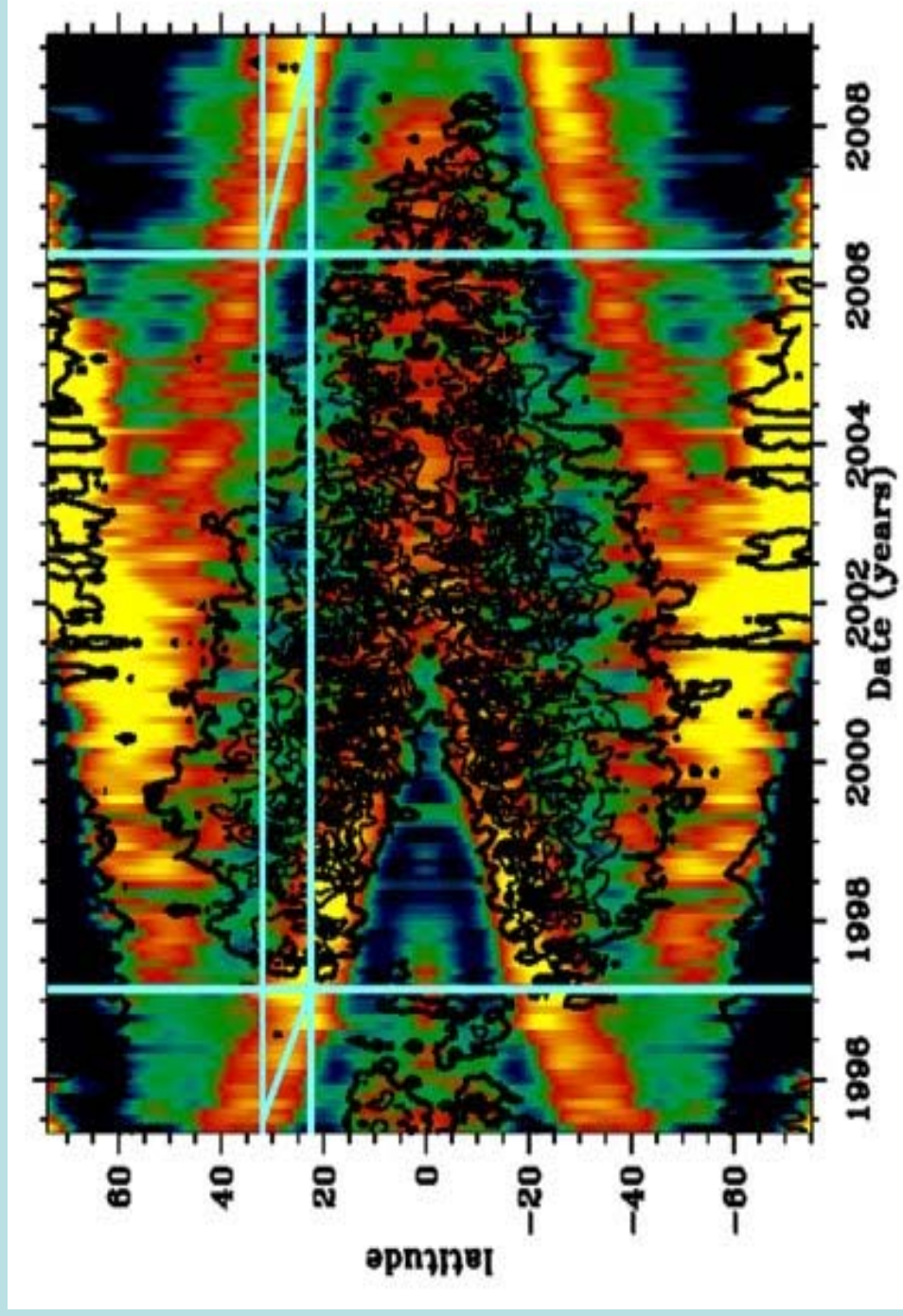
- **Polar Fields**

Green Corona Brightness to Determine Time of Maximum



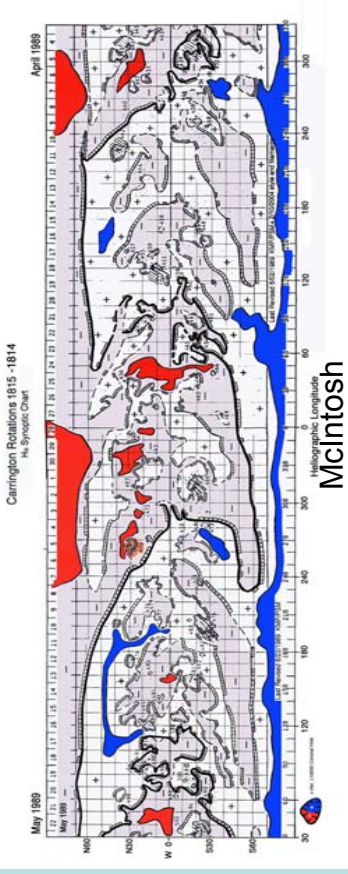
Torsional Oscillation Polar Branch

Where is it? (Chicken & Egg)

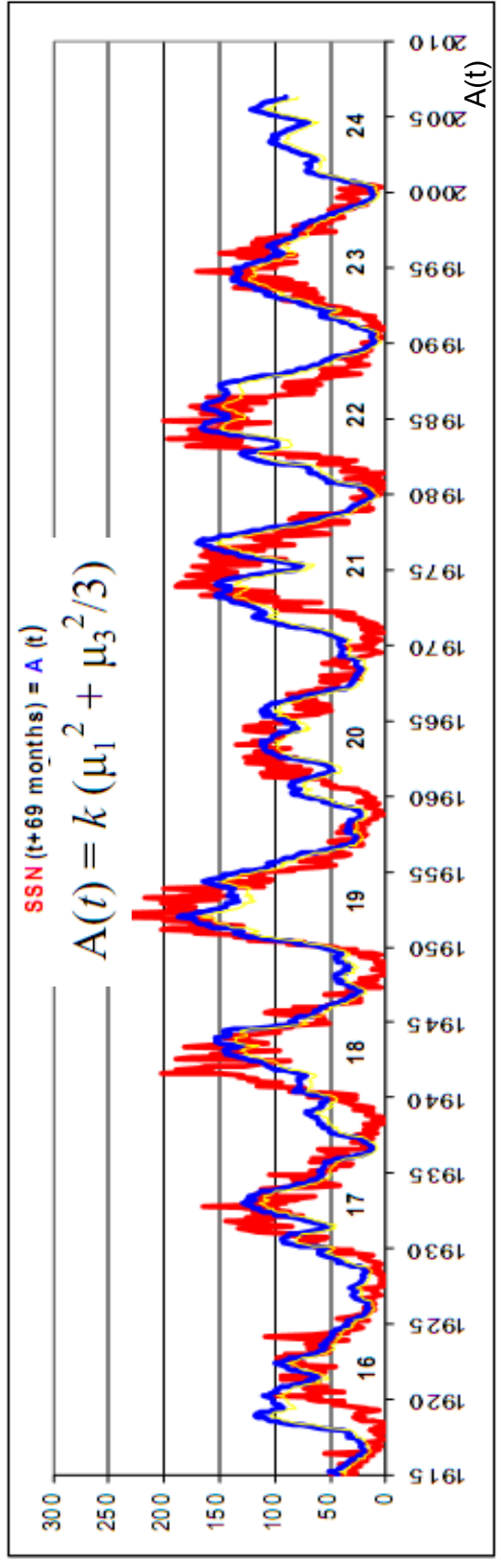


Howe, 2009

Large-Scale 'Magnetic' Field from Neutral Lines on H α Maps

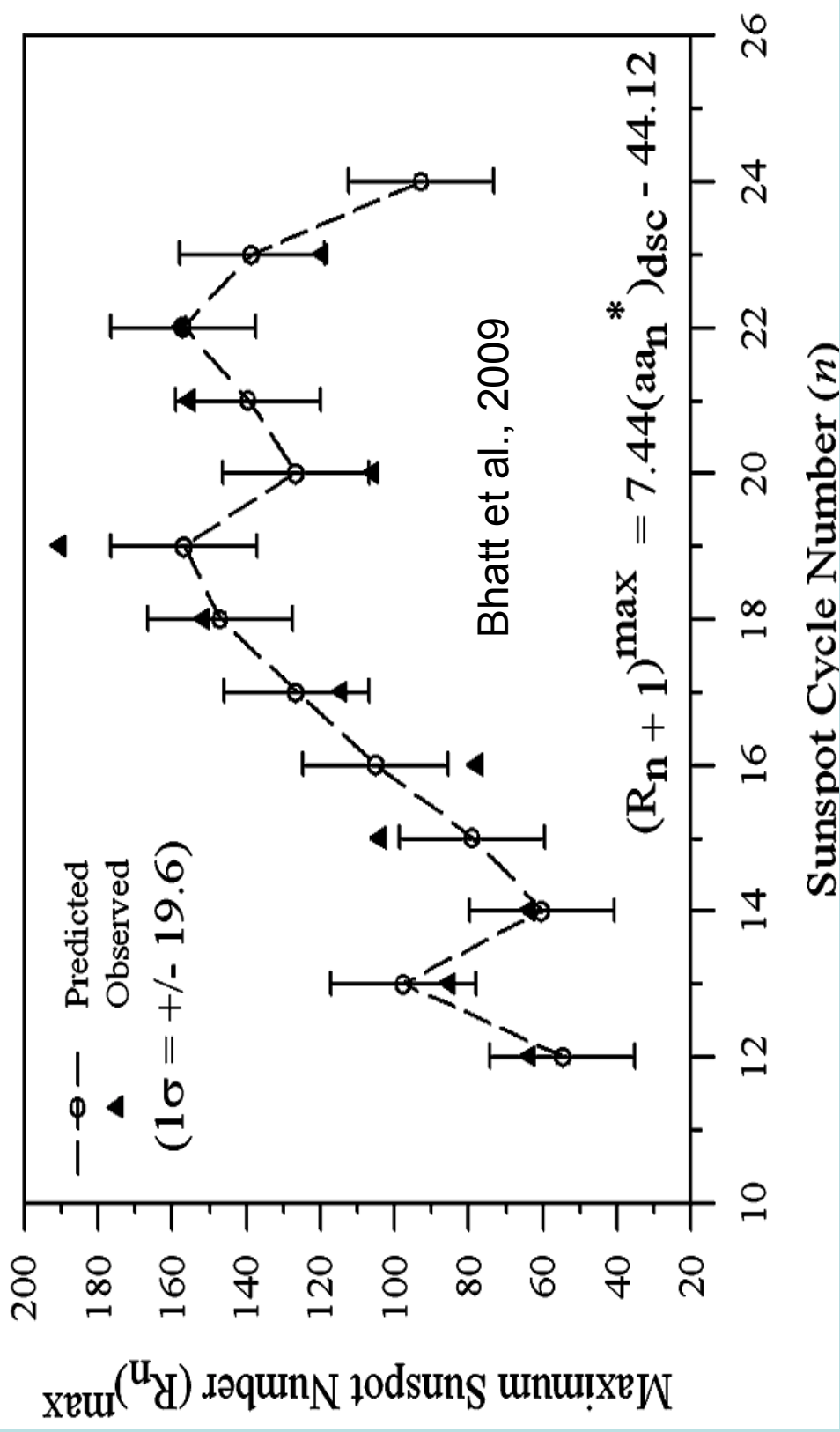


Assigning fields of +1 and -1 to areas between neutral lines, calculate the global dipole μ_1 and octupole μ_3 components. They predict the cycle 69 months ahead

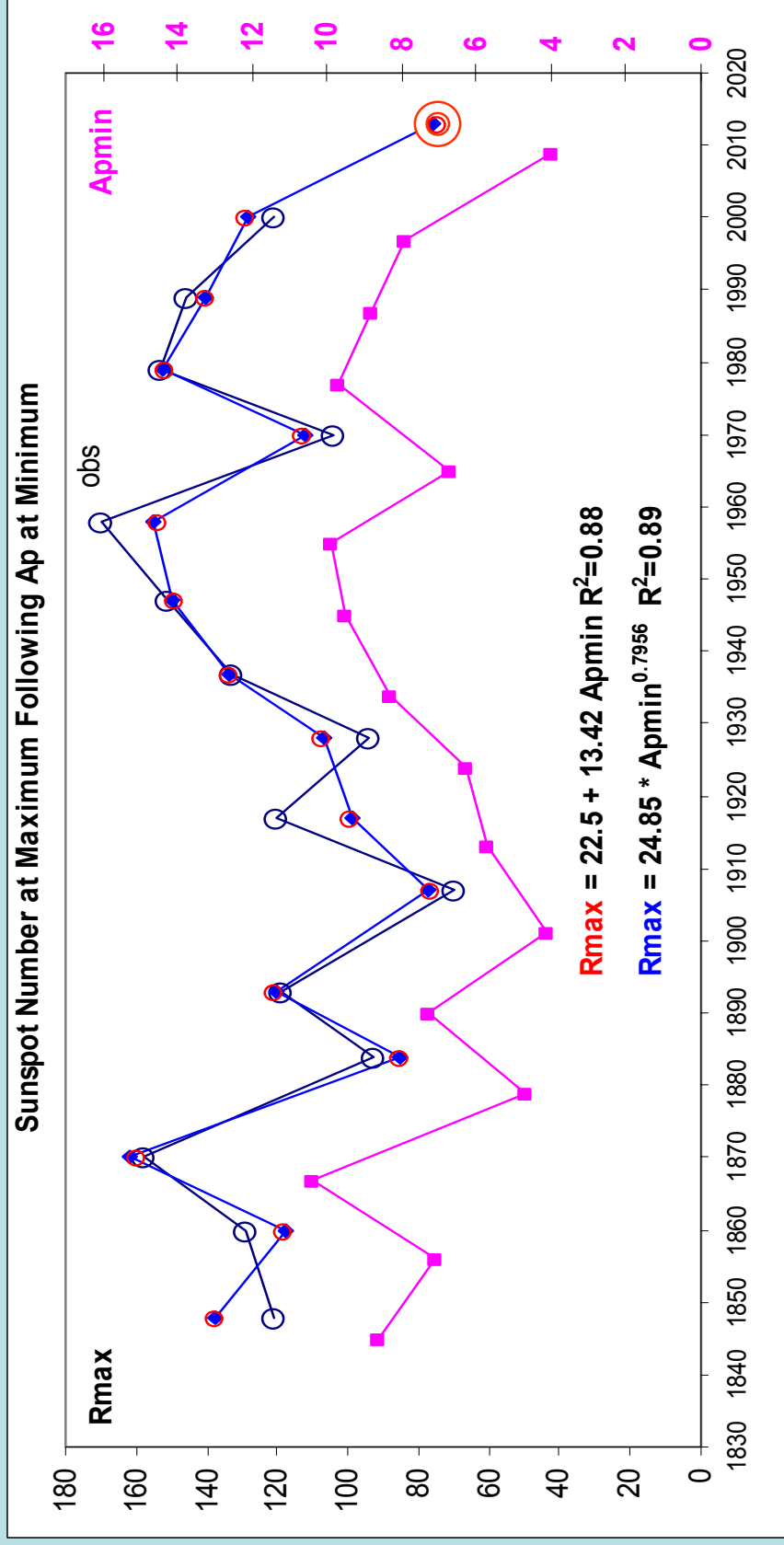


Tlatov et al., 2006

Geomagnetic Activity During Descending Phase of Cycle

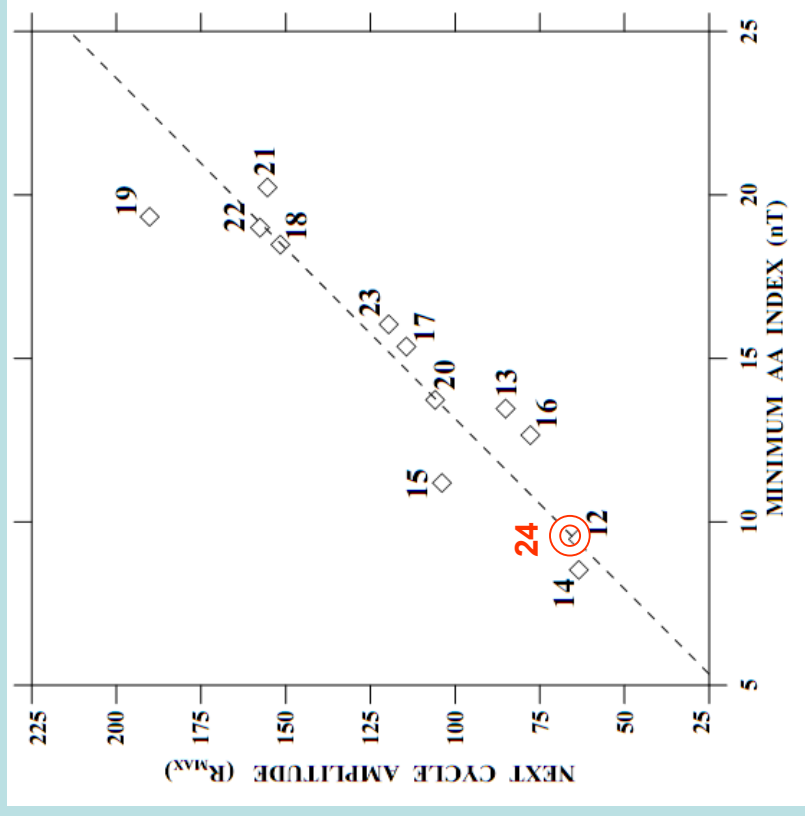
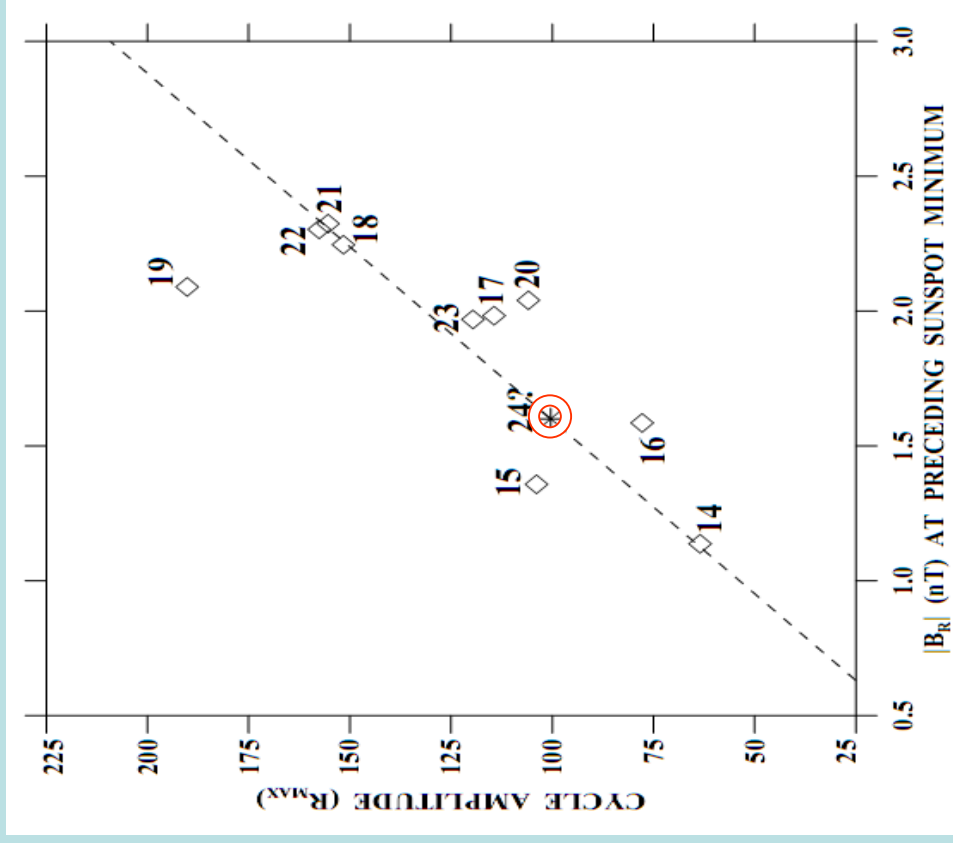


Or Just at Minimum



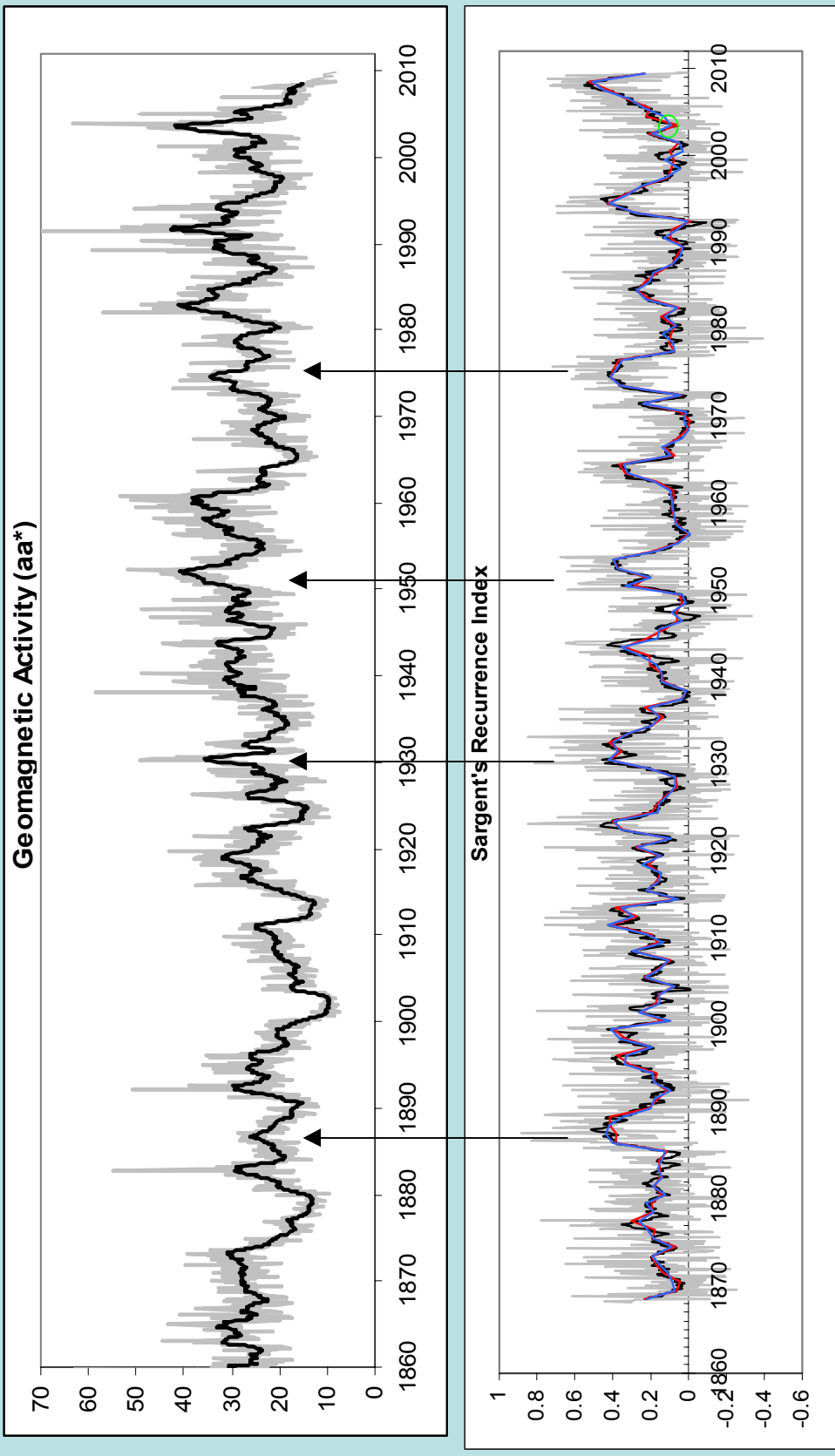
Svalgaard, 2009

AA-index as Proxy for Open Heliospheric Magnetic Flux

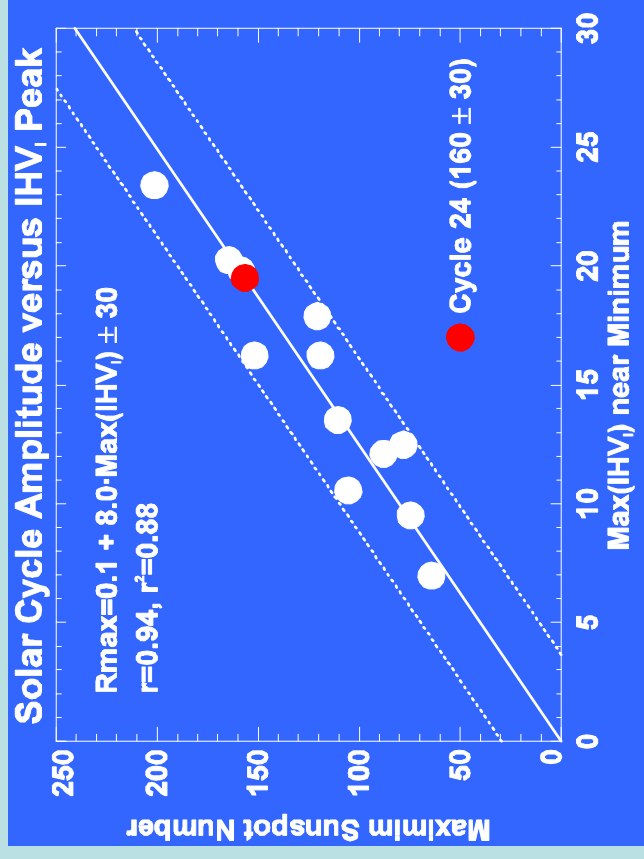
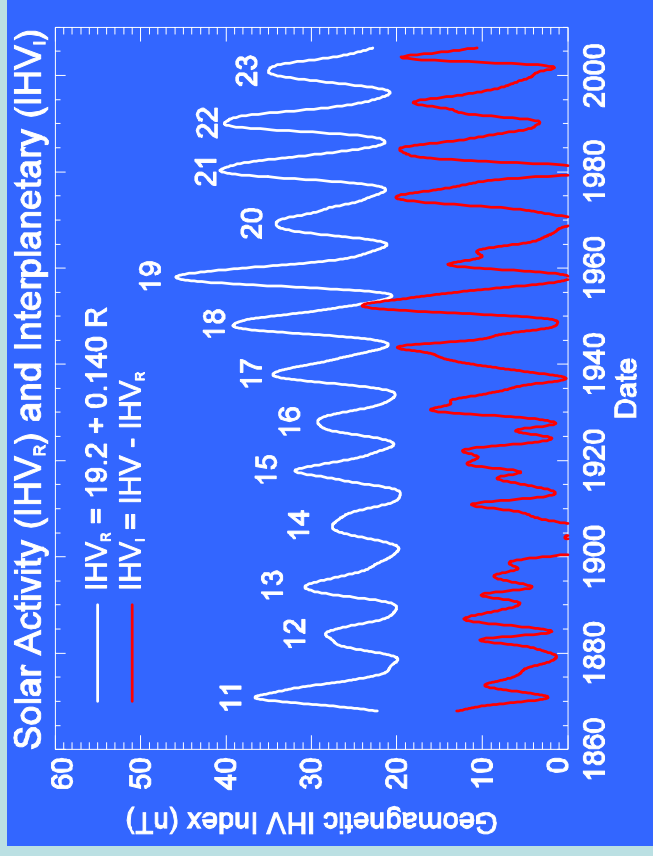


Min AA based on last 12 months

Recurrent High-Speed Streams Nearing Solar Minimum Create High Geomagnetic Activity

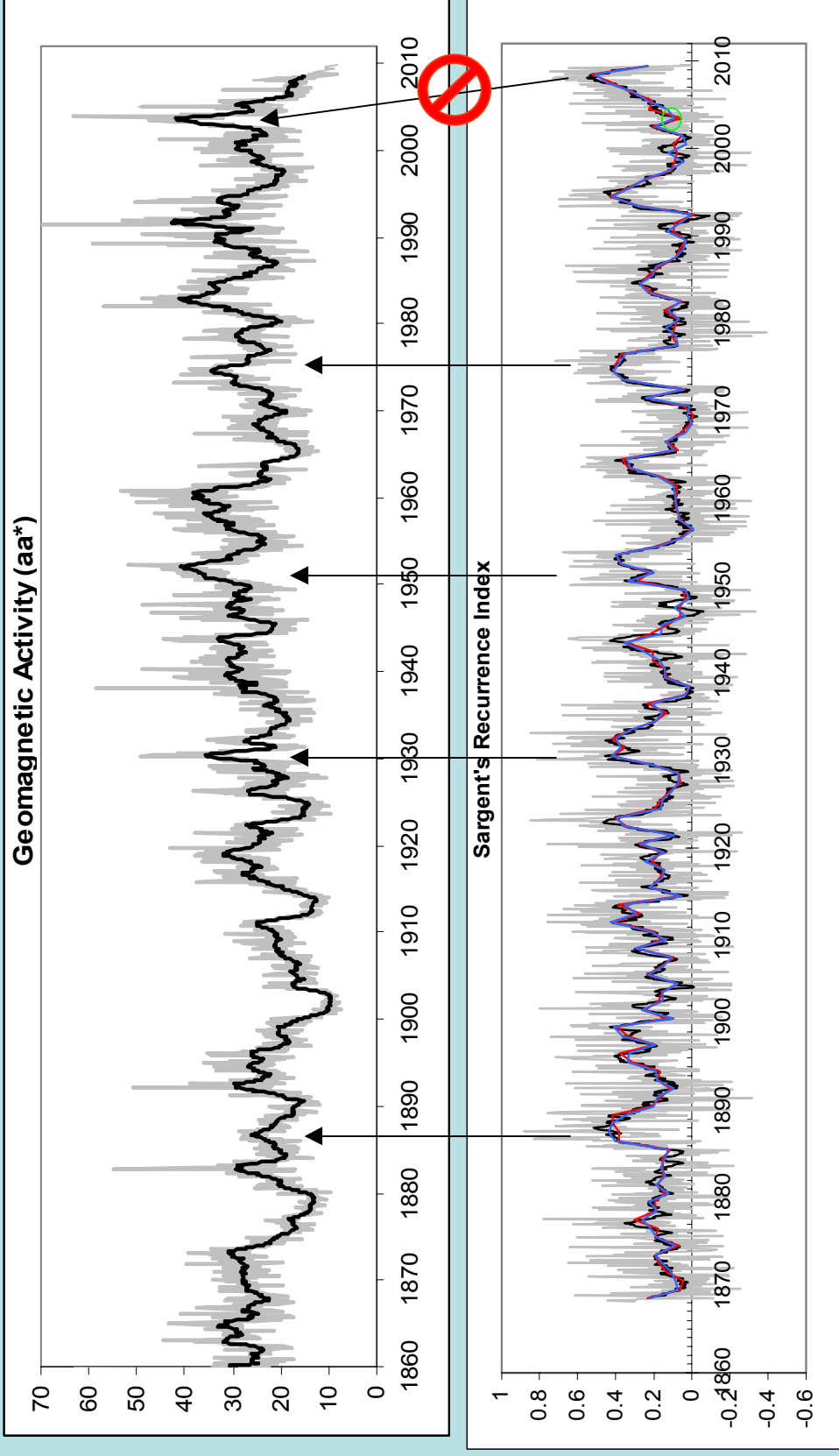


The Size of these Activity Peaks [Corrected for Sunspot Activity] has been used as a Precursor of the Next Cycle [Physics is Obscure Though]



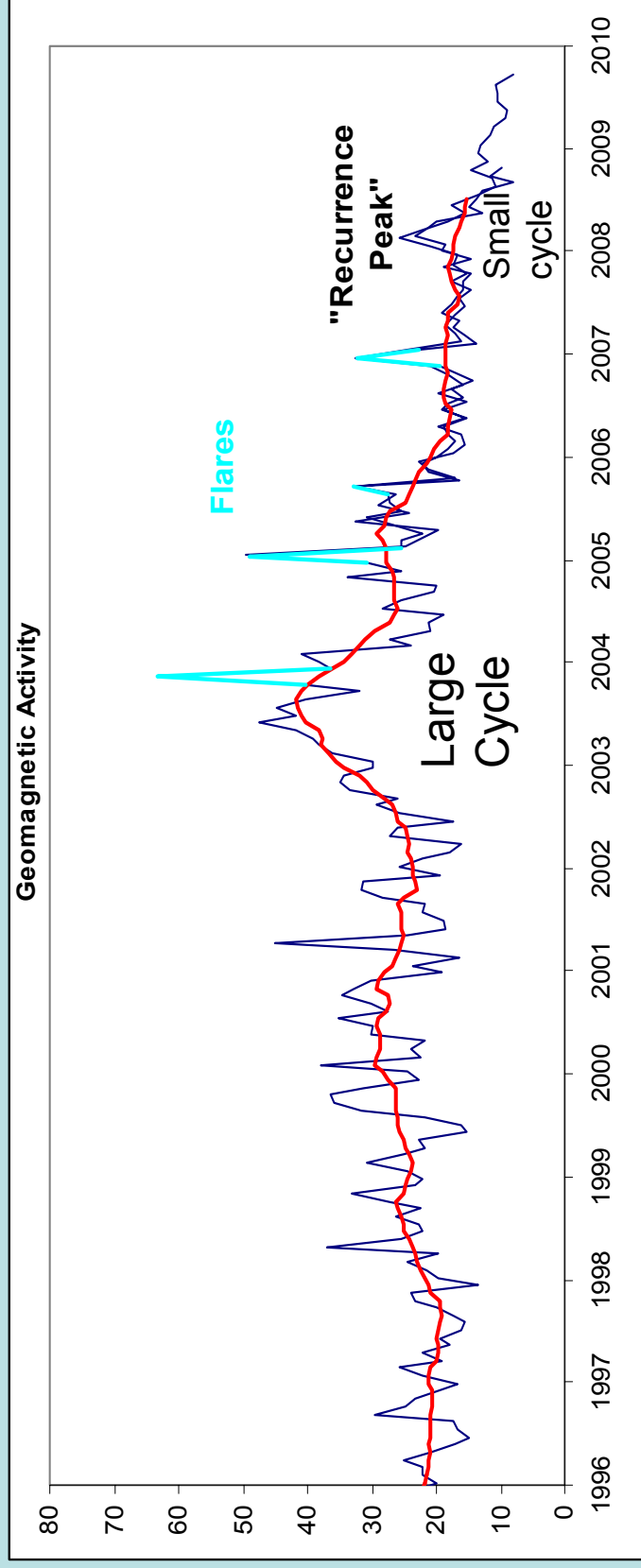
Hathaway et al.

Picking the Wrong Peak [From Filtered Data] Can Lead You Astray

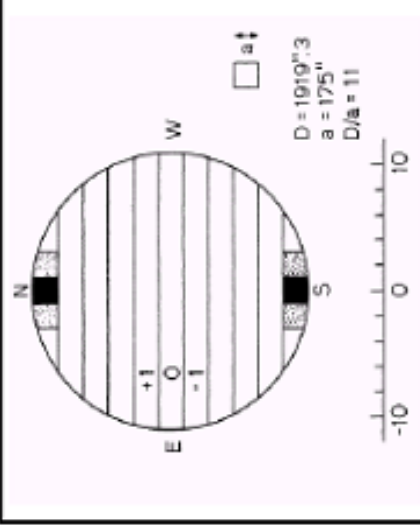


“Picking the Peak”

- Using the large peak in 2003 predicted a large cycle [Rmax ~ 160], but perhaps the peak to use [based on the Recurrence Index] is the one in 2008 that predicts a small cycle [Rmax ~ 80]



Definition of Polar Fields



Wilcox Solar Observatory (WSO)

Large aperture: 3'

Operational Definition of Polar Fields:
Average field in pole-most apertures (black squares)

Mount Wilson Observatory (MWO)

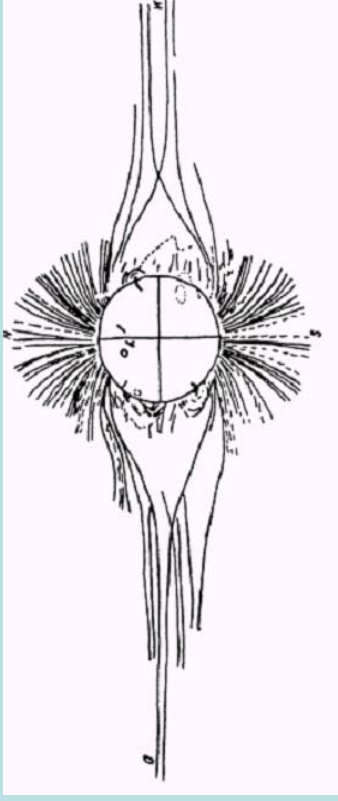
Small aperture: 0.2'

Operational Definition of Polar Fields:
Average field of pixels inside aperture that matches that of WSO

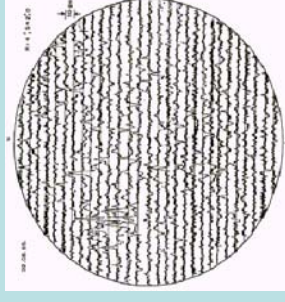
Measurements of Polar Fields



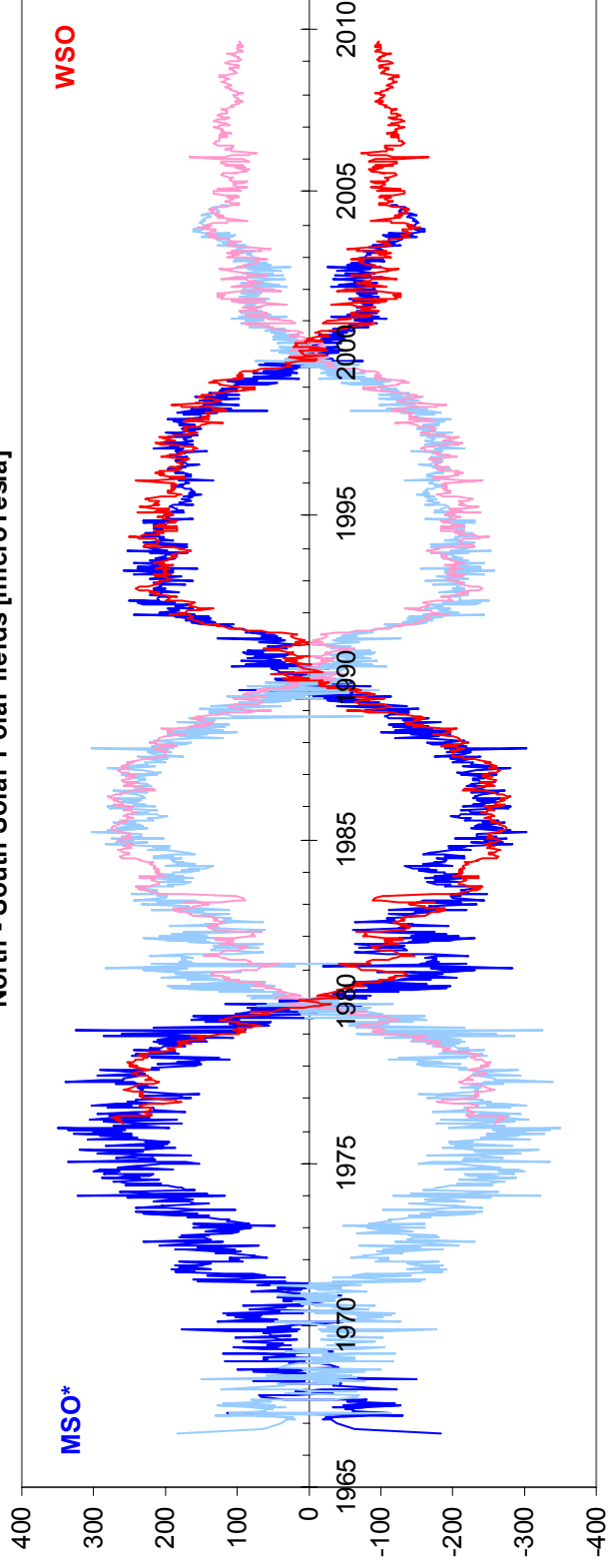
1953



1965

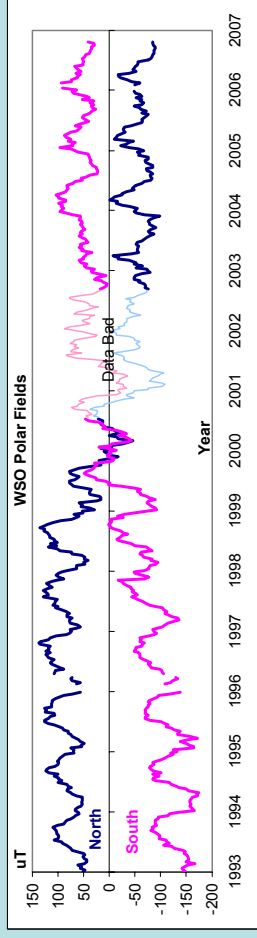
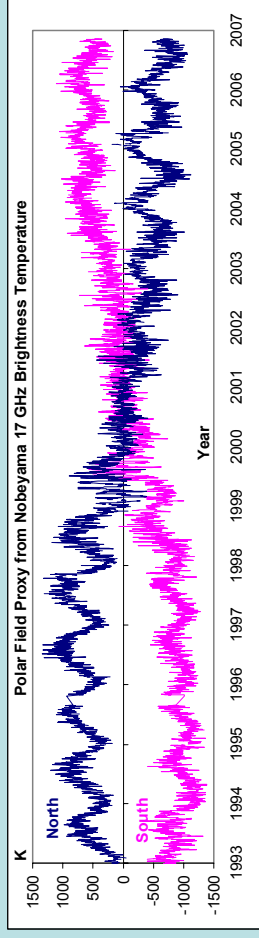
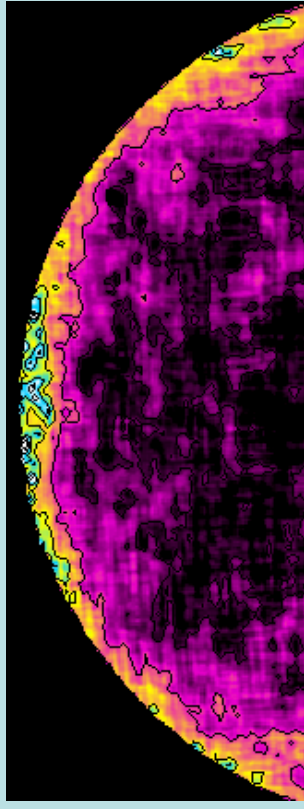


North - South Solar Polar fields [microTesla]



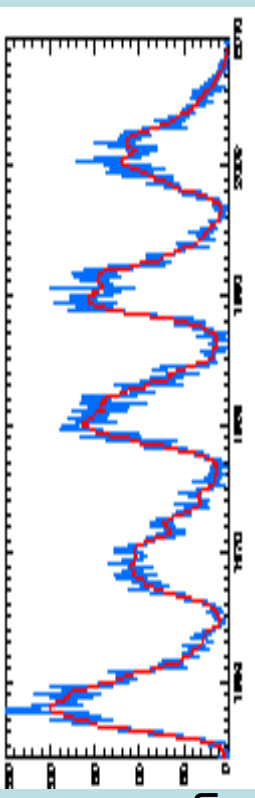
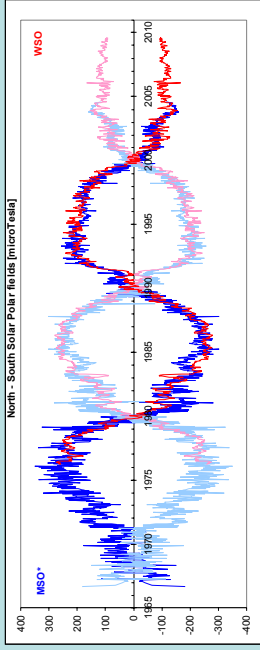
Another Measure of the Polar fields

17 GHz Radio Flux



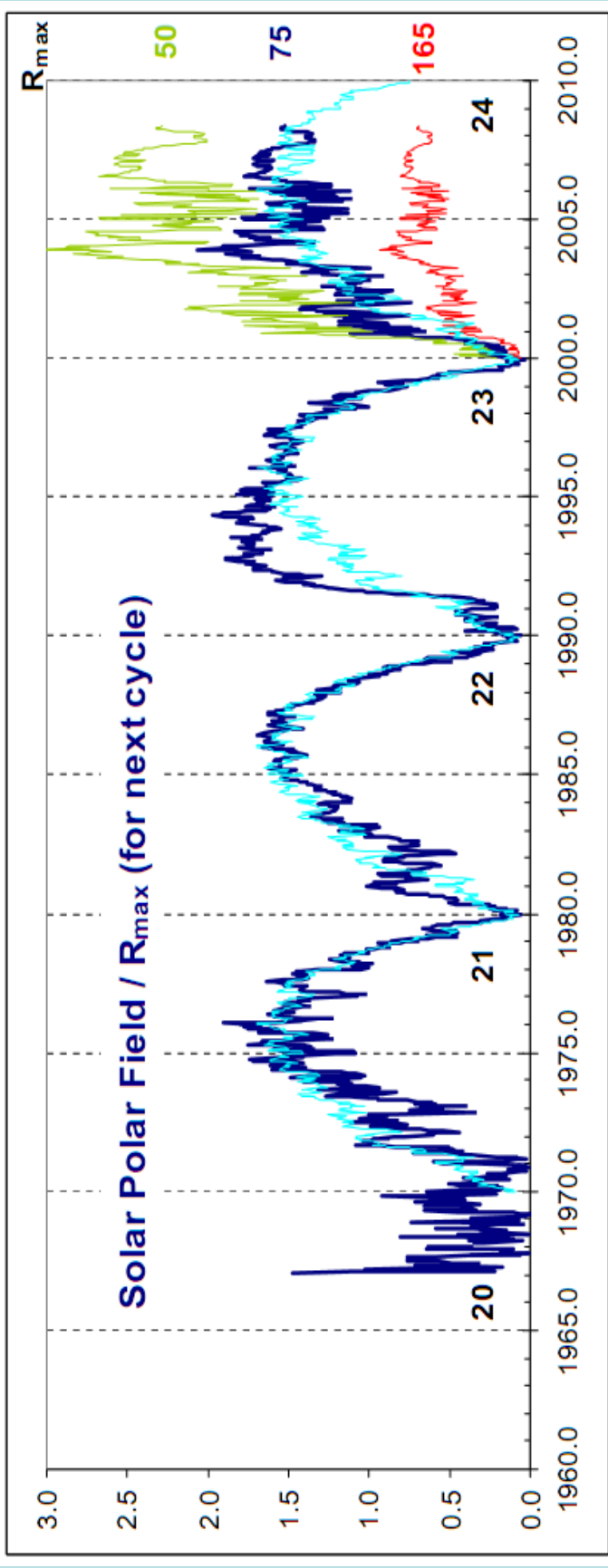
Nobeyama Radioheliograph, Japan

Polar Field Scaled by Size of Next Cycle is Possibly an Invariant



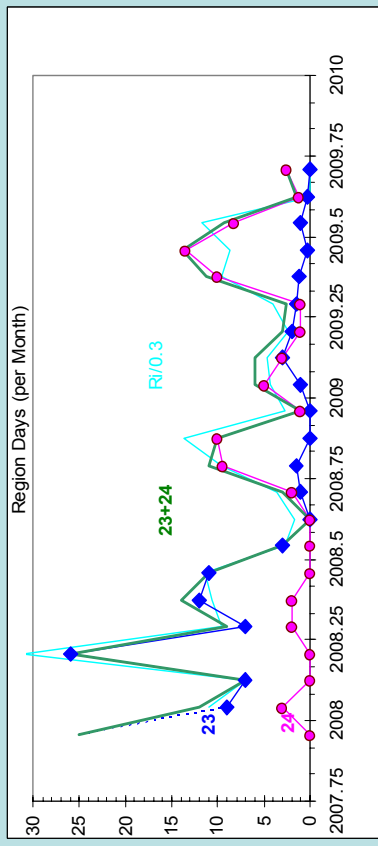
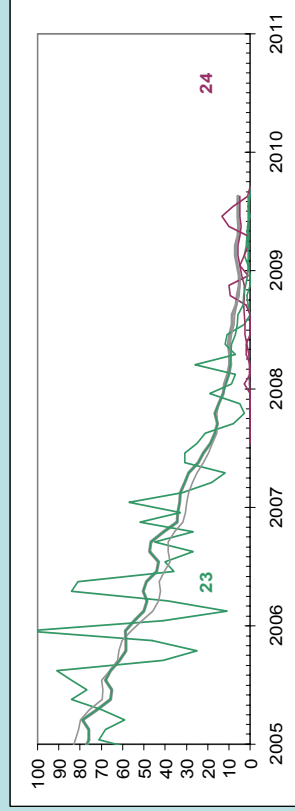
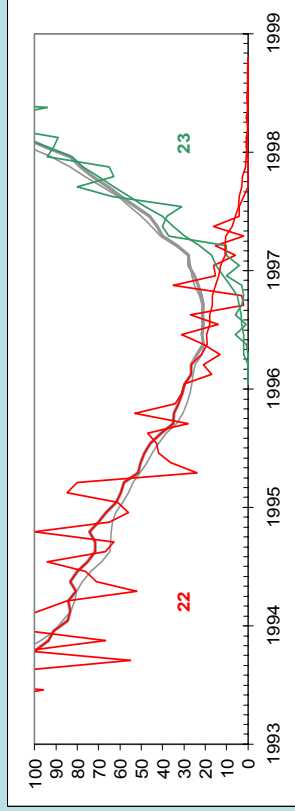
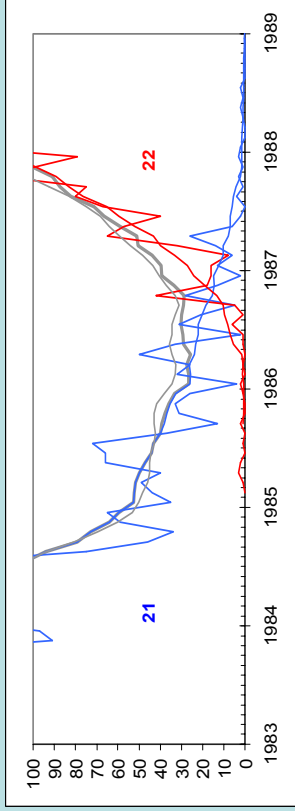
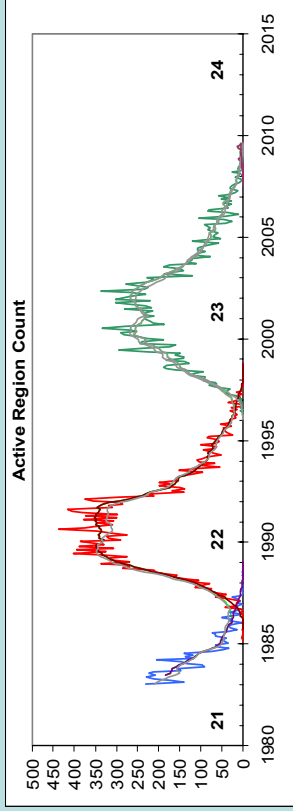
$R_{\max 24} = 75$

Our Prediction



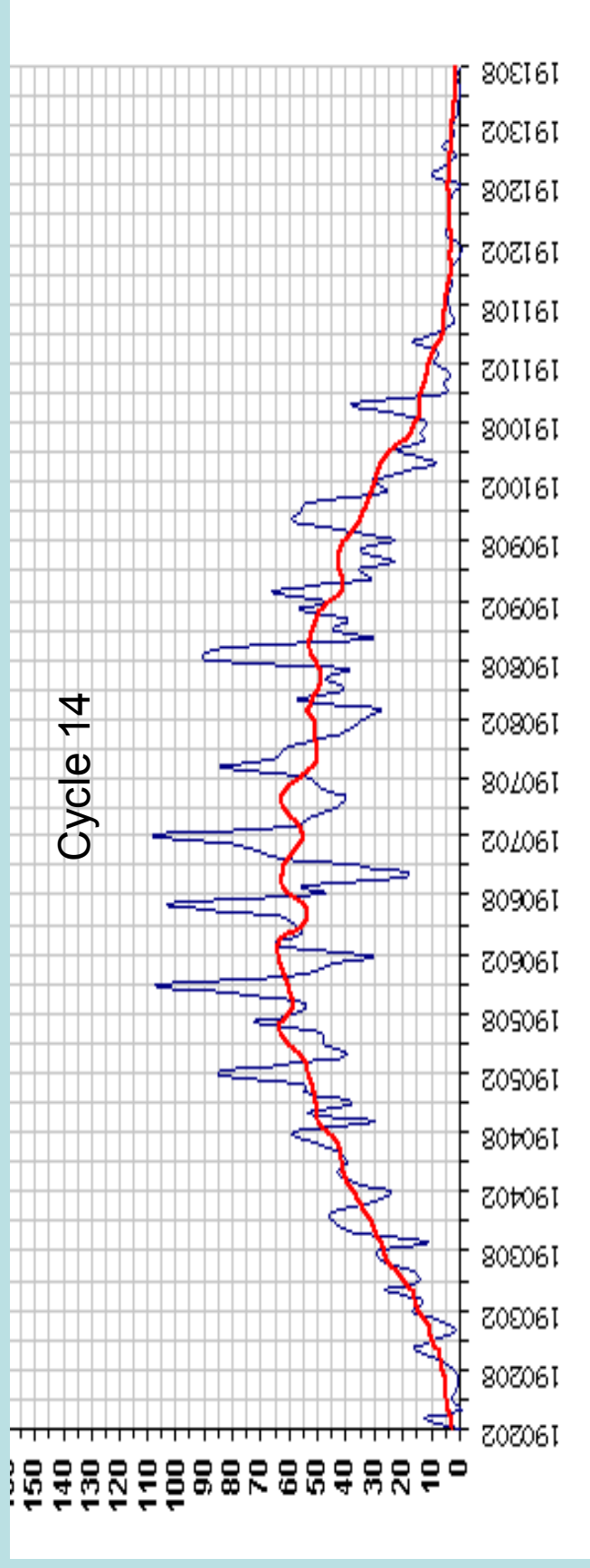
Cycle Transitions

The current minimum is very low [the lowest in a century], and it looks like Minimum is now behind us



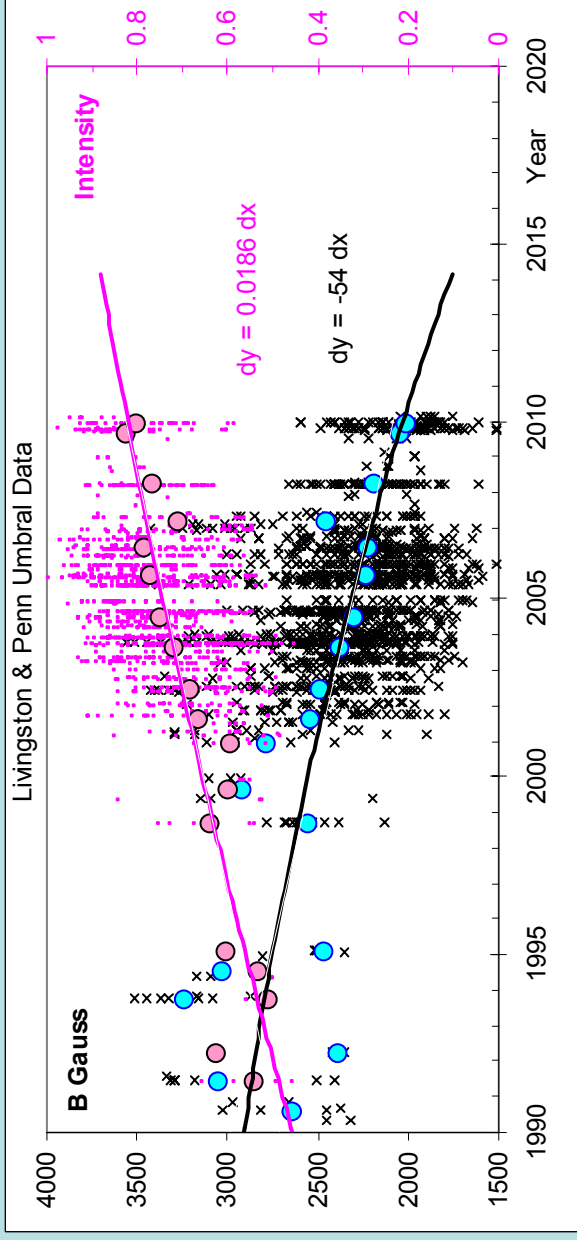
What Will Cycle 24 Look Like?

- Perhaps like cycle 14, starting 107 years ago
- Note the curious oscillations, will we see some this time?
- If so, I can just imagine the confusion there will be with ‘verification’ of the prediction



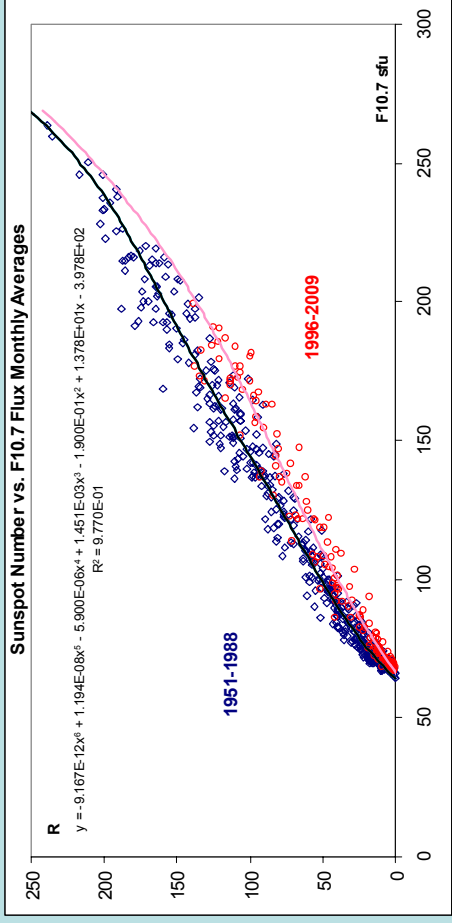
If We Can Just See the Spots...

- Sunspots are getting warmer, thus becoming harder to see. Will they disappear? Or will the Sunspot Number just be biased and too small...



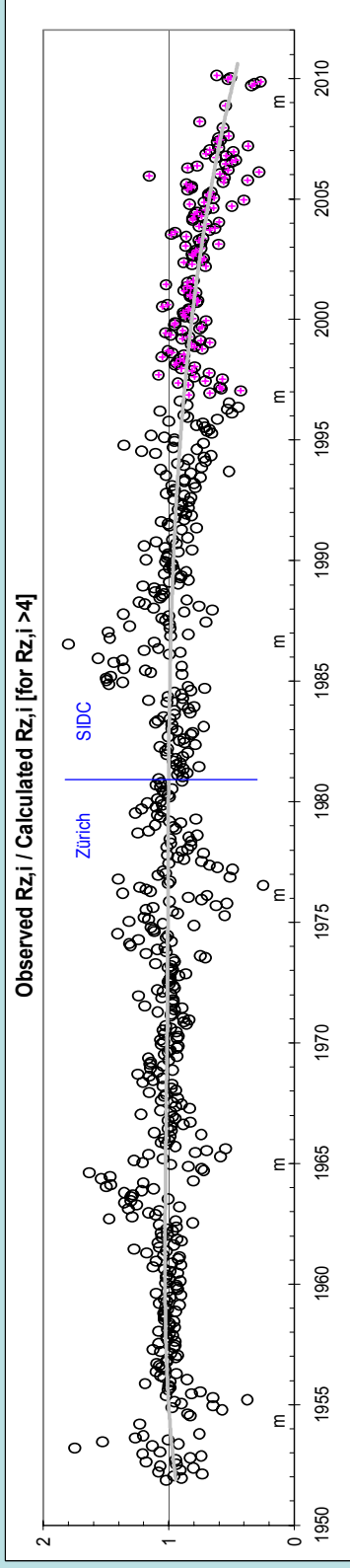
William Livingston, Pers. Comm. 2010

F10.7 Flux Relationship with Sunspot Numbers is Changing



Ratio of observed SSN and SSN computed from F10.7 using formula for 1951-1988

Recent SSN already too low ?



So What Do We Predict? SSN or F10.7 Flux or Magnetic Regions?

- Since the prediction is based on the magnetic field, we are really predicting a proxy for the field:
- F10.7 120 sfu
- Magnetic Regions 6
- Sunspot Number Who knows?
- Was the Maunder Minimum like this?

Conclusion

"It cannot be said that much progress has been made towards the disclosure of the cause, or causes, of the sun-spot cycle. Most thinkers on this difficult subject provide a quasi-explanation of the periodicity through certain assumed vicissitudes affecting internal processes. In all these theories, however, the course of transition is arbitrarily arranged to suit a period, which imposes itself as a fact peremptorily claiming admittance, while obstinately defying explanation"

Agnes M. Clerke, *A Popular History of Astronomy During the Nineteenth Century*, page 163, 4th edition, A. & C. Black, London, 1902.

Abstract

We discuss a number of aspects related to our understanding of the solar dynamo. We begin by illustrating the lack of our understanding. Perhaps as exemplified by SWPC's Solar Cycle 24 Prediction Panel. They received and evaluated ~75 prediction papers with predicted sunspot number maxima ranging from 40 to 200 and with a near normal distribution around the climatological mean indicative of the poor State of the Art. Flux Transport Dynamo Models were recently hyped? or hoped? to promise significant progress, but they give widely differing results and thus seem inadequate in their current form. In these models, higher meridional flow speed should produce strong polar fields and a short solar cycle, contrary to the observed behavior of increased meridional flow speed, low polar fields, and long-duration cycle 23. Poorly understood Precursor-methods again seem to work as they have in previous cycles. I review the current status of these methods. Predictions are usually expressed in terms of maximum Sunspot Number or maximum F10.7 radio flux, with the implicit assumption that there is a fixed [and good] relation between these measures of solar activity. If Livingston & Penn's observations of a secular change in sunspot contrast hold up, it becomes an issue which of these two measures of solar activity should be predicted and what this all means. The coming cycle 24 may challenge cherished and long-held beliefs and paradigms. .